

ISSN 2706-6282
e-ISSN 2706-6290

Тернопільський національний медичний університет імені І. Я. Горбачевського

Вісник медичних і біологічних досліджень

Науково-практичний журнал

Заснований у 2019 році
Періодичність випуску: щоквартально

Том 6, № 1

Тернопіль – 2024

ISSN 2706-6282
e-ISSN 2706-6290

Засновник:

Тернопільський національний медичний університет імені І. Я. Горбачевського

Рік заснування: 2019

*Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Тернопільський національний медичний університет імені І. Я. Горбачевського
(протокол № 4 від 27 лютого 2024 р.)*

**Свідоцтво про державну реєстрацію
друкованого засобу масової інформації
серії КВ № 23992-13832Р**

Журнал входить до переліку наукових фахових видань України

Категорія «Б». Спеціальності: 222 – «Медицина», 223 – «Медсестринство», 091 – «Біологія та біохімія»
(наказ Міністерства освіти і науки України
№ 886 від 02 липня 2020 та № 1188 від 24 вересня 2020)

**Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах:** Національна бібліотека України імені В. І. Вернадського,
Фахові видання України, BASE, Index Copernicus, Ulrich's Serials Analysis System, UCSB Library,
Dimensions, German Union Catalogue of Serials, Doaj, University of Oslo Library, University of Hull Library,
SOLO - Search Oxford Libraries Online, European University Institute, Leipzig University Library,
Cambridge University Library

Вісник медичних і біологічних досліджень / [редкол.: Л. Я. Федонюк (голов. ред.) та ін.]. – Тернопіль :
Тернопільський національний медичний університет імені І. Я. Горбачевського, 2024. – Т. 6, № 1. – 87 с.

Адреса редакції:

Тернопільський національний медичний університет імені І. Я. Горбачевського
46001, майдан Волі, 1, м. Тернопіль, Україна
E-mail: info@bibr.com.ua
<https://bibr.com.ua/uk>

ISSN 2706-6282
e-ISSN 2706-6290

I. Horbachevsky Ternopil National Medical University

Bulletin of Medical and Biological Research

Scientific-Practical Journal

Founded in 2019
Frequency: quarterly

Volume 6, No. 1

Ternopil – 2024

ISSN 2706-6282
e-ISSN 2706-6290

Founder:

I. Horbachevsky Ternopil National Medical University

Year of foundation: 2019

*Recommended for printing and distribution
via the Internet by the Academic Council
I. Horbachevsky Ternopil National Medical University
(Minutes No. 4 of February 27, 2024)*

**Certificate of state registration
of the print media**

Series KB No. 23992-13832P

The journal is included in the list of scientific professional publications of Ukraine
Category "B". Specialties: 222 – "Medicine", 223 – "Nursing", 091 – "Biology and Biochemistry"
(Order of the Ministry of Education and Science of Ukraine
No. 886 as of July 02, 2020 and No.1188 of September 24, 2020)

**The journal is presented international scientometric databases, repositories
and scientific systems:** National Library of Ukraine named after V. I. Vernadskyi,
Professional publications of Ukraine, BASE, Index Copernicus, Ulrich's Serials Analysis System,
UCSB Library, Dimensions, German Union Catalogue of Serials, Doaj, University of Oslo Library,
University of Hull Library, SOLO - Search Oxford Libraries Online, European University Institute,
Leipzig University Library, Cambridge University Library

Bulletin of Medical and Biological Research / Ed. by L. Fedoniuk. (Editor-in-Chief) et al. Ternopil:
I. Horbachevsky Ternopil National Medical University, 2024. Vol. 6, No. 1. 87 p.

Editors office address:

I. Horbachevsky Ternopil National Medical University
46001, 1 Maidan Voli, Ternopil, Ukraine
E-mail: info@bibr.com.ua
<https://bibr.com.ua/en>

Редакційна колегія

Головний редактор

Лариса Федонюк

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Відповідальний редактор

Тарас П'ятковський

Кандидат медичних наук, доцент, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Відповідальний секретар

Неля Глипка

Кандидат біологічних наук, асистент, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Національні члени редколегії

Ігор Господарський

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Надія Деміхова

Доктор медичних наук, професор, Сумський державний університет, Україна

Інна Криницька

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Петро Лихацький

Доктор біологічних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Людмила Мазур

Кандидат медичних наук, доцент, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Лілія Мартинюк

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Марія Марущак

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Олександр Шідловський

Доктор медичних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Світлана Ястремська

Доктор педагогічних наук, професор, Тернопільський національний медичний університет імені І. Я. Горбачевського, Україна

Дмитро Дмитрієв

Доктор медичних наук, професор, медичний директор, комунальне некомерційне підприємство "Подільський регіональний центр онкології Вінницької обласної Ради", Україна

Олександр Назарчук

Доктор медичних наук, доцент, Вінницький національний медичний університет ім. М. І. Пирогова, Україна

Гаяне Акопян

Доктор медичних наук, професор, Державна установа «Інститут спадкової патології національної академії медичних наук України», Україна

Міжнародні члени редколегії

Параскеві Папаіонаїдоу

Доктор медичних наук, професор, Університет Арістотеля в Салоніках, Греція

Рамаз Чіхладзе

Доктор медичних наук, професор, Тбіліський медичний університет, Грузія

Киялбек Сакибаєв

Кандидат медичних наук, доцент, Ошський державний університет, Киргистан

Ілона Гартмане

Кандидат медичних наук, лікар-дерматолог, Ризький університет імені Страдіня, Латвія

Джузеппе Фабіо Парізі

Доктор медичних наук, лікар-педіатр пульмонолог, Лікарня Сан-Марко, Університет Катанія, Італія

Editorial Board

Editor-in-Chief

Larysa Fedoniuk

Doctor of Medical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Managing Editor

Taras Pyatkovskyy

PhD in Medical Sciences, Associate Professor, I. Horbachevsky National Medical University, Ukraine

Executive Secretary

Nelia Hlyvka

PhD in Biological Sciences, Assistant Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

National Members of the Editorial Board

Ihor Hospodarsky

Doctor of Medical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Nadiya Demikhova

Doctor of Medical Sciences, Professor, Sumy State University, Ukraine

Inna Krynytska

Doctor of Medical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Petro Lykhatskyi

Doctor of Biological Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Lyudmyla Mazur

PhD in Medical Sciences, Associate Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Liliya Martynyuk

Doctor of Biological Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Mariya Marushchak

Doctor of Medical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Oleksandr Shidlovskiy

Doctor of Medical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Svitlana Yastremska

Doctor of Pedagogical Sciences, Professor, I. Horbachevsky Ternopil National Medical University, Ukraine

Dmytro Dmytriiev

Doctor of Medical Sciences, Professor, Medical Director, communal nonprofit enterprise "Podilsky Regional Center of Oncology of the Vinnytsia Regional Council", Ukraine

Oleksandr Nazarchuk

Doctor of Medical Sciences, Associate Professor, National Pirogov Memorial Medical University, Ukraine

Hayane Akopyan

Doctor of Medical Science, Professor, State University "Institute of Hereditary Pathology of the National Academy of Medical Sciences of Ukraine", Ukraine

International Members of the Editorial Board

Paraskevi Papaioannidou

Doctor of Medical Sciences, Professor, Aristotle University of Thessaloniki, Greece

Ramaz Chikhladze

Doctor of Medical Sciences, Professor, Tbilisi State Medical University, Georgia

Kyialbek Sakibaev

PhD in Medical Sciences, Associate Professor, Osh State University, Kyrgyzstan

Ilona Hartmane

PhD in Medical Sciences, Dermatologist, Riga Stradins University, Latvia

Giuseppe Fabio Parisi

Doctor of Medical Sciences, Pediatric Pulmonologist, San Marco Hospital, University of Catania, Italy

ЗМІСТ / CONTENTS

І. Галабіцька, Л. Бабінець Вплив екзокринної недостатності підшлункової залози на перебіг остеоартрозу за умов коморбідності	8
I. Halabitska, L. Babinets Pancreatic exocrine insufficiency impact on the course of osteoarthritis in comorbidity	8
О. Галушко, Ю. Гуртовий Розробка та валідація математичної моделі для прогнозування розвитку рефлюкс-езофагіту на основі даних відеоезофагогастроуденоскопії	15
O. Halushko, Yu. Hurtovyi Development and validation of a mathematical model for predicting the development of gastro-oesophageal reflux disease based on oesophagogastroduodenoscopy	15
О. Зубков, В. Торчинський Вплив нахилу таза на зміну центра ротації кульшового суглоба в передопераційному плануванні	24
O. Zubkov, V. Torchynskiy Effect of pelvic tilt on changing the centre of rotation of the hip joint in preoperative planning	24
Н. Мар'єнко Вікові зміни великих півкуль головного мозку чоловіків та жінок: морфометричне дослідження магнітно-резонансних томограм	34
N. Maryenko Age-related changes in the cerebral hemispheres of male and female brains: A morphometric study using magnetic resonance imaging scans	34
Т. П'ятковський, О. Покришко, С. Данилков Дослідження знезараження води за допомогою електролітичного озонування для застосування в умовах воєнного часу	43
T. Pyatkovskyy, O. Pokryshko, S. Danylko Exploring water disinfection through electrolytic ozonation for application in wartime conditions	43
Л. Сарафінюк, І. Степаненко, О. Хапіцька, О. Лежньова, Р. Власенко Антропометричні особливості кінцівок у волейболісток різних соматотипів	52
L. Sarafyniuk, I. Stepanenko, O. Khapitska, O. Lezhnova, R. Vlasenko Anthropometric features of limbs in volleyball players of different somatotypes	52
Н. Смолюк, А. Шульгай Особливості професійного вигорання медичних сестер стаціонарів в умовах війни	64
N. Smoliuk, A. Shulhai Peculiarities of professional burnout of nurses in war conditions	64
Л. Федонюк, О. Руденко, О. Ружицька, П. Жученко Морфологічні зміни структурних компонентів клапанів серця людини, які пов'язані з хронічною гемодинамічною травмою	73
L. Fedoniuk, O. Rudenko, O. Ruzhytska, P. Zhuchenko Morphological changes in structural components of human heart valves associated with chronic haemodynamic trauma	73



Pancreatic exocrine insufficiency impact on the course of osteoarthritis in comorbidity

Iryna Halabitska*

PhD in Medical Sciences, Assistant Professor
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0002-9028-7230>

Liliia Babinets

Doctor of Medical Science, Professor, Head of the Department
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0002-0560-1943>

Abstract. The relationship between chronic diseases and osteoarthritis is a common phenomenon, especially among the elderly. Patients with osteoarthritis require an integrated approach that includes the collaboration of various medical specialists, such as general practitioners, rheumatologists, orthopaedic surgeons, gastroenterologists and traumatologists. The study aims to investigate the impact of diseases associated with exocrine pancreatic insufficiency on the course of primary osteoarthritis in comorbidity. A total of 304 patients with primary osteoarthritis and exocrine pancreatic insufficiency were analysed. All patients were divided into five groups depending on the type of concomitant pathology. The study determined that in the group of patients with primary osteoarthritis, a statistically significant improvement in the course of the disease according to various indicators, such as the radiological stage of osteoarthritis, functional joint failure, Lequesne index, and NSAID index, compared with those in the groups with other comorbidities, was present ($p < 0.05$). This confirms the significant impact of the studied comorbidities on the course of primary osteoarthritis. The post-hoc analysis determined the ranking of the impact of comorbidities accompanied by exocrine pancreatic insufficiency on the clinical course of primary osteoarthritis by various indicators, such as the radiological stage of osteoarthritis, functional joint failure, Lequesne index, and the index of non-steroidal anti-inflammatory drugs. Ranking results: type 2 diabetes mellitus > chronic pancreatitis > hepatobiliary diseases > gastro-duodenal diseases ($p < 0.05$). The study highlighted a mild exocrine insufficiency of the pancreas according to faecal α -elastase in the group of patients with isolated primary osteoarthritis. The study also established the ranking of the impact of pathologies accompanied by exocrine pancreatic insufficiency on the course of primary osteoarthritis by the level of faecal α -elastase: chronic pancreatitis < type 2 diabetes mellitus < hepatobiliary diseases < gastro-duodenal diseases ($p < 0.05$). The results can be used in the clinical practice of doctors of various specialities: general practitioners, rheumatologists, gastroenterologists

Keywords: joint syndrome; functional insufficiency of the pancreas; gastroenterological diseases; type 2 diabetes mellitus

✦ INTRODUCTION

The American College of Rheumatology (ACR) [1] describes osteoarthritis (OA) as a disease caused by biological and mechanical factors. These factors disrupt the normal balance between the processes of destruction and restoration of chondrocytes, the extracellular matrix of articular cartilage and subchondral bone [2, 3].

L.A. Michener *et al.* [4], and V. Duong *et al.* [5] described OA as a serious destructive and dystrophic disease that can affect any human joint, regardless of its structure and function. This disease has a chronic course with a tendency to exacerbate and progression of articular cartilage, other joint tissues and those surrounding it. A common outcome of OA

Suggested Citation:

Halabitska I, Babinets L. Pancreatic exocrine insufficiency impact on the course of osteoarthritis in comorbidity. Bull Med Biol Res. 2024;6(1):8–14. DOI: 10.61751/bmbr/1.2024.08

*Corresponding author



progression is a complete loss of joint shape and function, which leads to disability. Currently, OA treatment aims to reduce symptoms, slowing progression and improving the quality of life of patients. There are no drugs that would cure this disease, which is a substantial medical problem, especially in the context of comorbidity with other diseases.

M.N. Wanjau *et al.* [6], B. Conley *et al.* [7], C.G. Boer *et al.* [8] have studied that the comorbidity of chronic diseases with OA is widespread, especially in adulthood. Patients with OA require the attention of specialists from various fields of medicine, such as general practitioners, rheumatologists, gastroenterologists, orthopaedic traumatologists, and surgeons. This is determined by the high integrative risk of developing acute conditions with the simultaneous use of medications that can cause complications. L.S. Babinets *et al.* [9], B. Wang *et al.* [10] demonstrate that osteoarthritis and pathology of the upper gastrointestinal tract are included in several comorbidity scales, such as FCI (Functional Comorbidity Index), Kaplan-Feinstein index and Burden Index – an index of total pain burden, which creates a global problem of prescribing medications, especially if gastroenterological pathology is accompanied by functional pancreatic insufficiency.

D.C. Whitcomb *et al.* [11] demonstrated that the main causes of exocrine pancreatic insufficiency (Pancreatic Exocrine Insufficiency, exPEI) are a decrease in the volume of pancreatic parenchyma, obstruction of the main pancreatic duct, reduced stimulation of exocrine pancreatic tissue and inactivation of pancreatic enzymes. ExPEI is divided into primary and secondary forms, so the pathogenetic variant of pancreatic insufficiency significantly affects the treatment strategy. The pathogenesis of exPEI is complex and involves many components. For successful treatment, exPEI pathogenesis analysis should be performed in each patient not only to prescribe enzyme replacement therapy but also to address other necessary aspects of treatment, such as the use of antisecretory agents, correction of intestinal composition, regulation of the microbiota, etc [12].

There are currently insufficient studies on the development and progression of exPEI under the influence of pain treatment in patients with OA and comorbidities accompanied by exPEI. This problem requires further study to better understand the relationship between the treatment of pain syndrome, OA, and the development and progression of exPEI in these patients. The study aims to investigate the impact of diseases accompanied by exocrine insufficiency on the course of primary osteoarthritis in comorbidity.

✦ MATERIALS AND METHODS

The study analysed 304 patients with primary osteoarthritis who had concomitant diseases with exocrine pancreatic insufficiency, outside the period of exacerbation. These patients were registered at the Primary Health Care Centre in Ternopil from 2019 to 2021. For comparison, a group of 30 healthy individuals with no clinical or anamnestic data on joint and gastrointestinal (GI) diseases and no instrumental signs of such diseases was used. All patients underwent a detailed analysis of their complaints and anamnesis and underwent objective, laboratory and instrumental examinations.

The criteria for inclusion of patients in the study were both genders with a confirmed diagnosis of primary osteoarthritis and the presence of diseases accompanied by

pancreatogenic, gastrogenic, hepatogenic, endocrine or enterogenic exocrine pancreatic insufficiency. Patients were excluded from the study if the following conditions were present: peptic ulcer of the stomach and duodenum, gastric malignancies, condition after dumping syndrome, cholelithiasis, liver cirrhosis, gastric resection, malignant liver tumours, viral hepatitis, cystic fibrosis, history of pancreatic resection, large cysts or tumours of the pancreas, condition after cholecystectomy, type I diabetes mellitus, subcompensated and decompensated type II diabetes mellitus, use of systemic glucocorticosteroids, celiac disease, ulcerative colitis, acute myocardial infarction, decompensation of cardiopulmonary diseases, chronic renal failure of stages III-V, rhythm disturbances, surgical intervention within the last month, pregnancy, thyroid pathology, severe exhaustion, bleeding disorders, mental and behavioural disorders, diseases of the blood and hematopoietic organs, hypertension of II-III degree, and refusal to participate in the study.

The diagnoses of osteoarthritis, chronic pancreatitis, non-stone cholecystitis, functional diseases of the gallbladder and biliary system, chronic gastritis and chronic duodenitis, and type 2 diabetes mellitus were made following the standards. Patients ranged in age from 25 to 77 years, with an average age of (52.47 ± 5.37) years. All study participants were divided into five groups according to the nature of the concomitant pathology accompanied by exocrine pancreatic insufficiency. Groups were formed following clinical and gender characteristics, severity of primary osteoarthritis and treatment.

Group 1 (OA) (n=62) consisted of patients with primary osteoarthritis unaccompanied by any other pathology with exocrine pancreatic insufficiency.

Group 2 (OA + CP) (n = 59) included patients with primary osteoarthritis who also had chronic pancreatitis (CP) as a comorbidity.

Group 3 (OA + HBD) (n=60) included patients with primary osteoarthritis who had biliary system diseases, such as chronic non-calcific cholecystitis, functional gallbladder disorders and others, accompanied by exocrine pancreatic insufficiency (hepato-biliary disease (HBD)).

Group 4 (OA + GDD) (n=61) included patients with primary osteoarthritis who had chronic gastritis and chronic duodenitis (gastro-duodenal disease (GDD)).

Group 5 (OA + T2DM) (n= 62) included patients with primary osteoarthritis and type 2 diabetes mellitus (T2DM).

An accepted classification was used to assess the radiological stage of osteoarthritis. Functional joint failure (FJF) was also determined according to the relevant criteria.

The NSAID index was also determined for each patient with primary osteoarthritis in comorbidity with diseases accompanied by exocrine pancreatic insufficiency. This index was calculated by counting the number of days during the year when the patient took the average therapeutic dose of NSAIDs to reduce the symptoms of primary osteoarthritis. The average therapeutic daily dose of NSAIDs was the average therapeutic dose: paracetamol – 2000 mg, ibuprofen – 1800 mg, ketoprofen – 200 mg, indomethacin – 100 mg, piroxicam – 15 mg, diclofenac – 100 mg, meloxicam – 10 mg, nimesulide – 150 mg, celecoxib – 300 mg. One day on which the average therapeutic dose of NSAIDs was taken was considered as

one point. The previous year's NSAID index, determined retrospectively, was compared to the current year's NSAID index, determined prospectively.

An enzyme-linked immunosorbent assay was used to determine the level of faecal α -elastase using standard branded kits. To assess the severity of primary osteoarthritis in the studied patients, the Lequesne algo-functional index was used [13]. This index is a self-reported questionnaire that includes questions divided into three main categories: pain or discomfort, the maximum distance for walking and performing daily activities.

The Shapiro-Wilk test was used to test whether the data distribution conforms to the normal distribution law. The mean value and standard error ($M \pm m$) were used to describe the data. To test statistical significance, a significance level (p) of less than 0.05 was used. To assess differences between the means of three or more independent samples with a normal distribution, a one-way ANOVA was used, followed by a Tukey's post hoc HSD (Honestly Significant Difference) test to identify statistical differences. In cases where the distribution of samples differed from the normal distribution, the Kruskal-Wallis H-test One-Way Analysis of Variance and Dunn's criterion were used, followed by the Holm method.

The study was an open-label retrospective cohort comparative controlled dynamic case-control clinical trial. All studies were carried out in compliance with the main provisions of the Council of Europe Convention on Human Rights and Biomedicine, performed following the World Medical Association Code of Ethics (Declaration of Helsinki) of the World Medical Association on the Ethical Principles for Research Involving Human Subjects (as amended) [14], Order of the Ministry of Health of Ukraine No. 690 of 23.09.2009. All patients gave informed consent to participate in the study. The study was approved by the decision of the Bioethics Commission of the I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine No. 75 of 1 November 2023.

RESULTS

The characteristics of the course of primary osteoarthritis among the study groups were analysed. The assessment of the duration of primary osteoarthritis and the number of affected joints in different groups did not reveal a statistically significant difference between these parameters ($p > 0.05$), which confirms the homogeneity and comparability of the groups in terms of these characteristics.

However, the analysis of the radiological stages of primary osteoarthritis revealed a statistically significant difference between the study groups ($p < 0.05$). The study determined that the first group of patients with isolated primary osteoarthritis had the lowest radiological stage compared to other groups with comorbidity of primary osteoarthritis and diseases accompanied by exocrine pancreatic insufficiency ($p < 0.05$).

This indicates the influence of comorbidities on the course of primary OA. The radiological stage of primary OA in the fifth group was 16.00% higher than in the second group, 11.94% higher than in the third group, 14.20% higher than in the fourth group, and 16.56% higher than in the first group. During the post hoc analysis of the radiological stage of primary OA in the study groups, the impact rating

of comorbidity was determined and prioritised: T2DM > CP > HBD > GDD ($p < 0.05$) (Fig. 1).

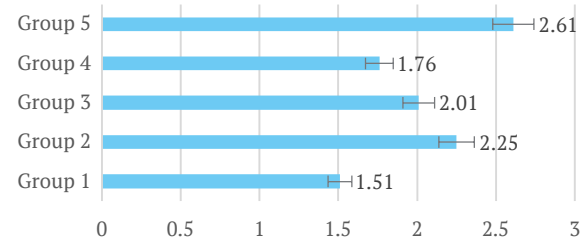


Figure 1. Radiological stage of OA in patients of the study groups

Source: compiled by the authors

The analysis of FJF in patients with primary OA revealed a statistically significant difference between these parameters in patients in different study groups ($p < 0.05$), establishing that the lowest level of FJF was statistically significantly observed in patients of the first group who did not have concomitant pathology. This indicates a significant impact of comorbidities accompanied by exocrine pancreatic disease (ExPEI) on functional joint disability in patients with primary OA. The study also analysed the percentage difference between the groups of patients with comorbidity compared to the group with isolated primary OA in terms of FJF. FJF in patients of the fifth group was 22.37% higher compared to the second group, 24.59% higher compared to the third group, 24.49% higher compared to the fourth group, and 27.27% higher compared to the first group. The post hoc analysis showed that comorbidities accompanied by exPEI in primary OA had the following impact rating: T2DM > CP > HBD > GDD ($p < 0.05$) (Fig. 2).

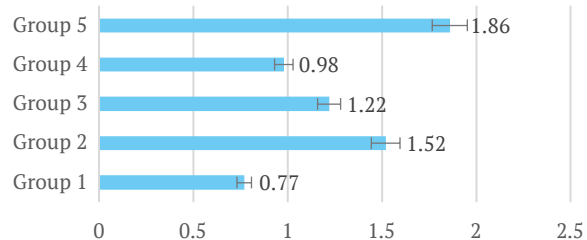


Figure 2. FJF in patients of the study groups

Source: compiled by the authors

In an analysis of the NSAID index, the study determined that in all study groups, this indicator was statistically significantly higher compared to the control group ($p < 0.001$). In addition, the lowest statistically significant level of the NSAID index was observed in patients in the first group with isolated primary osteoarthritis compared with those with comorbidity, indicating a significant impact of comorbidity on the frequency of NSAID use. There was no statistically significant difference in the level of the NSAID index between the third and fourth groups ($p > 0.05$). The percentage difference between the groups of patients with comorbidity and the group with isolated primary OA according to the NSAID index was also analysed.

It was also found that the NSAID index in the fifth group was 15.25% higher than in the second group, in the

second group it was 11.31% higher than in the third group, in the third group it was 2.35% higher than in the fourth group, and in the fourth group it was 12.94% higher than in the first group. As a result of the post hoc analysis, the rating of the impact of comorbid pathology accompanied by exocrine pancreatic insufficiency on the NSAID index was determined, addressing the priority: T2DM > CP > HBD > GDD ($p < 0.05$) (Fig. 3).

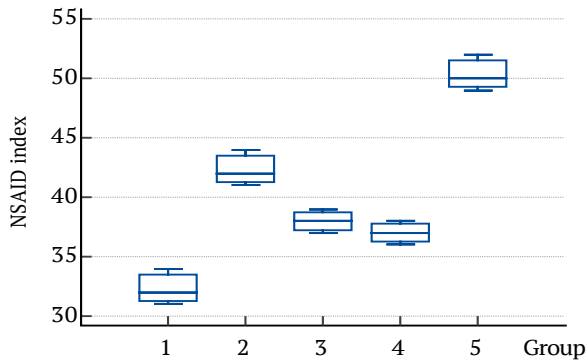


Figure 3. Confidence intervals of the NSAID index in the study groups of patients with primary OA

Source: compiled by the authors

The analysis of pancreatic exocrine insufficiency (ex-PEI) indices in groups of patients with primary osteoarthritis in the presence of comorbidities was performed. The study determined that the level of faecal α -elastase statistically significantly decreased in all study groups ($p < 0.001$), indicating the presence of exocrine pancreatic insufficiency in all patients with primary osteoarthritis. A statistically significant decrease in faecal α -elastase levels was also found in the first group of patients with primary osteoarthritis without concomitant pathology compared to the control group. This decrease was consistent with a mild degree of exocrine pancreatic insufficiency, which can occur as a result of long-term use of medications for the treatment of osteoarthritis, such as NSAIDs, glucocorticoids, chondroprotectors and chondrostimulants. (Fig. 4).

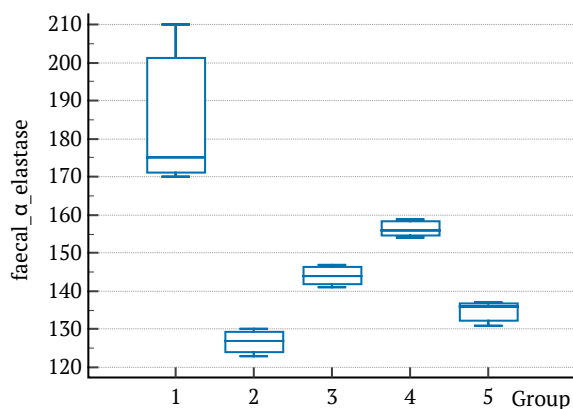


Figure 4. Confidence intervals of faecal α -elastase in patients of the study groups

Source: compiled by the authors

In the groups of patients with primary osteoarthritis in comorbidity with diseases accompanied by exocrine pancreatic insufficiency, a statistically significant difference between the levels of faecal α -elastase was found ($p < 0.05$). The level of faecal α -elastase was 5.47% lower in the second group compared to the fifth group, 4.35% lower in the fifth group compared to the third group, 9.63% lower in the third group compared to the fourth group, and 12.82% lower in the fourth group compared to the first group. The rating of the influence of pathology accompanied by exocrine pancreatic insufficiency on the level of faecal α -elastase in patients with osteoarthritis was determined: CP > T2DM > HBD > GDD ($p < 0.05$).

The results of the analysis of the Lequesne index showed a statistically significant increase in this indicator in all study groups compared to the control group ($p < 0.001$). There was also a statistically significant difference in the level of this indicator between the different study groups ($p < 0.05$). The lowest statistically significant level of the Lequesne index was observed in patients of the first group with isolated primary osteoarthritis compared with those with comorbidity ($p < 0.05$), which confirms the effect of concomitant pathology accompanied by exocrine pancreatic insufficiency on the course of primary osteoarthritis according to the Lequesne index (Fig. 5).

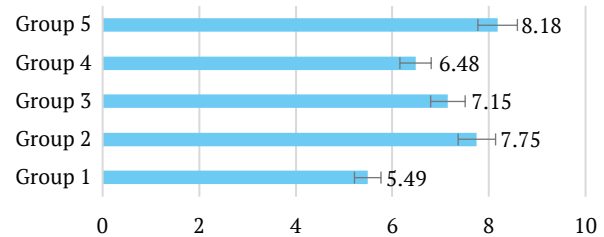


Figure 5. Lequesne index in patients of the study groups

Source: compiled by the authors

The percentage difference between the groups of patients with comorbidity and the group with isolated primary osteoarthritis according to the Lequesne index was analysed (Fig. 3). The individual index in Group 5 was 5.55% higher than in Group 2, 8.39% higher than in Group 2, 10.34% higher than in Group 3, and 18.03% higher than in Group 4. An additional post hoc analysis revealed the following rating of the impact of comorbid pathology accompanied by exocrine pancreatic insufficiency on the course of primary osteoarthritis according to the Lequesne index, which was determined by priority: T2DM > CP > HBD > GDD ($p < 0.05$). Thus, the comorbidity of OA and diseases accompanied by exocrine pancreatic insufficiency has a mutually burdensome effect on the course of both OA and gastroenterological diseases, which should be addressed in the management of such patients and the selection of safe drugs for the treatment of the study patients.

DISCUSSION

In the context of comparative studies, scientists investigated the comorbidity of osteoarthritis and other diseases on the course and progression of diseases in the context of comorbidity in terms of OA stage, FJF, Lequesne index and

ExPEI in patients with the studied comorbidities. S. Swain *et al.* [15], L.K. King *et al.* [16] point out that comorbidity in patients with OA is indeed a serious problem, and the identification of the main groups of comorbidities may contribute to a better understanding and management of these conditions. The main groups are those that have prognostic significance, as they represent groups of diseases that can interact with each other and affect the course of OA and the treatment of this disease. The first group, related to cardiovascular and cerebrovascular diseases, can be particularly dangerous for patients with OA, as it includes conditions that can worsen osteoarthritis and increase the risk of complications. NSAIDs, which are widely used to treat OA, may be limited in their use in this group of patients, which raises questions about the choice of optimal therapy. The second group, related to digestive system disorders, can also have a significant impact on OA, as gastrointestinal problems cause additional restrictions on the use of medications and therapies. The third group, which includes metabolic disorders such as obesity and diabetes mellitus, is also important because these conditions can worsen the chronic course of OA and increase the risk of complications. The data obtained are consistent with the literature, which indicates the progression of osteoarthritis in patients with comorbid and polymorbid conditions in terms of OA stage, FJD, Lequesne and ExPEI index, as well as the NSAID index.

L.K. King [16], and L.K. King *et al.* [17] found that OA may have different common risk factors for different diseases. Most authors point out that the presence of comorbidity can be explained by advanced age, a risk factor for the development of OA and other diseases [15, 17]. It has also been studied that comorbid gastroenterological diseases contribute to the progression of the radiological stage of OA, FJF, and the Lequesne index stage of OA. The association of OA with gastrointestinal diseases is usually explained by the long-term use of analgesics, especially NSAIDs. An analysis of the literature revealed many studies that highlighted the association of OA with gastrointestinal diseases, and this comorbidity is usually explained by the long-term use of analgesics, especially NSAIDs. Studies have revealed uneven reporting of symptomatic gastrointestinal disorders, which requires proper diagnosis and reporting in patients with OA and their impact on OA stage, FJF, Lequesne index and ExPEI, and especially on changes in the NSAID index. L.K. King *et al.* [17] found that concomitant hypertension, gastrointestinal disease, depressed mood, and more problematic joint pain sites were associated with higher opioid use in Canadian patients with knee osteoarthritis.

Comorbidities that occur along with OA pose additional challenges and, according to many experts, often complicate the process of choosing a treatment. The risk of therapy failure increases if the patient has diabetes mellitus, arterial hypertension, chronic digestive tract diseases, depression or obesity, as well as a history of gastrointestinal bleeding, myocardial infarction or renal failure [18, 20, 21]. These diseases pose a risk of complications when using NSAIDs [21]. The results of this study are consistent with the literature, with the NSAID index. However, the development and progression of exocrine pancreatic insufficiency in OA is an issue that has not been sufficiently investigated and requires further research.

L.E. Diamond *et al.* [18], and A. Mobasheri *et al.* [19] studied the common pathogenic links between OA and comorbidities, which can be useful for improving the treatment of patients with comorbidity of several chronic conditions. This is a promising approach, as it demonstrates the general mechanisms of development and the impact of different diseases on each other. This integrated approach can lead to the development of more effective and individually tailored treatment plans for patients with comorbidity. Such research is also economically feasible, as improved treatment efficacy can reduce the cost of medical care and provide a more sustainable and less complex approach to managing chronic conditions in patients [20, 21]. The results of the study also indicate the need for special attention to patients with OA in comorbidity with diseases accompanied by exPEI, especially when prescribing therapeutic drugs.

A.L. Arruda *et al.* [22] investigated the common genetic determination between the development of osteoarthritis, type 2 diabetes mellitus and obesity and found a genetically mediated relationship between the increased likelihood of development and progression of all diseases in the setting of such comorbidity. The study of genetic determination of the development of comorbidities in OA is a promising area and is tangentially consistent with the results of our studies, as the influence of comorbid pathology on the stage of OA, FJF, Lequesne index and ExPEI was revealed.

The fact that the number and severity of comorbidities increase with age emphasises the need for more rapid and careful monitoring of patient's health in older age groups. In the presence of several chronic conditions, the risk of complications increases, the quality-of-life decreases, and the prognosis of the disease worsens. Interdisciplinary cooperation between doctors of different specialities is also important to ensure optimal treatment and prevent complications [19, 22]. The study of common pathogenic links between OA and comorbidities can be very useful for improving the treatment of patients with comorbidity of several chronic conditions. This is a promising approach, as it demonstrates the general mechanisms of development and the impact of different diseases on each other. This integrated approach can lead to the development of more effective and individually tailored treatment plans for patients with comorbidity. Such research is also economically feasible, as improved treatment efficacy can reduce the cost of medical care and provide a more sustainable and less complex approach to managing chronic conditions in patients. There are currently insufficient studies on the development and progression of exPEI under the influence of pain treatment in patients with OA and comorbidities accompanied by exPEI. This problem requires further study to better understand the relationship between the treatment of pain syndrome, OA, and the development and progression of exPEI in these patients.

✦ CONCLUSIONS

The study determined that patients with isolated primary osteoarthritis had a statistically significant milder course of the disease in terms of such parameters as radiological stage of OA, FJF, Lequesne index and NSAID index compared with patients with comorbidity ($p < 0.05$).

This indicates a significant impact of concomitant pathology accompanied by exocrine pancreatic insufficiency on the development of primary osteoarthritis in comorbidity. Additional analysis revealed a rating of the impact of comorbid pathology accompanied by exocrine pancreatic insufficiency on the clinical course of primary osteoarthritis according to the radiological stage of OA, FJF, Lequesne index and NSAID index, which was determined by priority: type 2 diabetes mellitus > chronic pancreatitis > hepatobiliary diseases > gastro-duodenal diseases ($p < 0.05$). In addition, in the group of patients with isolated primary osteoarthritis, a mild degree of pancreatic exocrine insufficiency was detected by faecal α -elastase, which may be a consequence of the long-term treatment of OA with NSAIDs, glucocorticosteroids, chondroprotective and other drugs that have potentially toxic effects on the digestive tract and contribute to the development of gastroenterological diseases, including conditions accompanied by exocrine pancreatic insufficiency.

The rating of the impact of pathology accompanied by exocrine pancreatic insufficiency on the course of primary osteoarthritis by the level of faecal α -elastase was established, which was as follows: chronic pancreatitis < type 2 diabetes mellitus < hepatobiliary diseases < gastro-duodenal diseases ($p < 0.05$). The results of this study can be implemented in the clinical practice of doctors of various specialities to consider the peculiarities of osteoarthritis in comorbidity with diseases accompanied by functional pancreatic insufficiency. Further research should examine the genetic determination of comorbidities in OA and propose a comprehensive therapy for the studied comorbidity.

◆ ACKNOWLEDGEMENTS

None.

◆ CONFLICT OF INTEREST

The authors declare no conflict of interest.

◆ REFERENCES

- [1] Kolasinski SL, Neogi T, Hochberg MC, Oatis C, Guyatt G, Block J, et al. 2019 American College of Rheumatology/ arthritis foundation guideline for the management of osteoarthritis of the hand, hip, and knee. *Arthritis Rheumatol.* 2020;72(2):220–33. DOI: [10.1002/art.41142](https://doi.org/10.1002/art.41142)
- [2] Abramoff B, Caldera FE. Osteoarthritis: Pathology, diagnosis, and treatment options. *Med Clin North Am.* 2020;104(2):293–11. DOI: [10.1016/j.mcna.2019.10.007](https://doi.org/10.1016/j.mcna.2019.10.007)
- [3] Mehwish B, Ali SS, Mirza Baig AA. Effect of hip joint mobilisations and strength training on pain, physical function and dynamic balance in patients with Knee Osteoarthritis: A randomized controlled trial. *J Pak Med Assoc.* 2023;73(4):749–54. DOI: [10.47391/JPMA.6223](https://doi.org/10.47391/JPMA.6223)
- [4] Michener LA, Heitzman J, Abbruzzese LD, Bondoc SL, Bowne K, Henning PT, et al. Physical therapist management of glenohumeral joint osteoarthritis: A clinical practice guideline from the American Physical Therapy Association. *Phys Ther.* 2023;103(6):pzad041. DOI: [10.1093/ptj/pzad041](https://doi.org/10.1093/ptj/pzad041)
- [5] Duong V, Oo WM, Ding C, Culvenor AG, Hunter DJ. Evaluation and treatment of knee pain: A review. *JAMA.* 2023;330(16):1568–80. DOI: [10.1001/jama.2023.19675](https://doi.org/10.1001/jama.2023.19675)
- [6] Wanjau MN, Möller H, Haigh F, Milat A, Hayek R, Lucas P, et al. The potential impact of physical activity on the burden of osteoarthritis and low back pain in Australia: A systematic review of reviews and life table analysis. *J Phys Act Health.* 2023;20(8):690–1. DOI: [10.1123/jpah.2022-0541](https://doi.org/10.1123/jpah.2022-0541)
- [7] Conley B, Bunzli S, Bullen J, O'Brien P, Persaud J, Gunatillake T, et al. Core recommendations for osteoarthritis care: A systematic review of clinical practice guidelines. *Arthritis Care Res.* 2023;75(9):1897–7. DOI: [10.1002/acr.25101](https://doi.org/10.1002/acr.25101)
- [8] Boer CG, Hatzikotoulas K, Southam L, Stefánsdóttir L, Zhang Y, Coutinho de Almeida R, et al. Deciphering osteoarthritis genetics across 826,690 individuals from 9 populations. *Cell.* 2021;184(18):4784–18.e17. DOI: [10.1016/j.cell.2021.07.038](https://doi.org/10.1016/j.cell.2021.07.038)
- [9] Babinets LS, Migenko BO, Borovyk IO, Halabitska IM, Lobanets NV, Onyskiv OO. The role of cytokin imbalance in the development of male infertility. *Wiad Lek.* 2020;73(3):525–28. DOI: [10.36740/WLek202003123](https://doi.org/10.36740/WLek202003123)
- [10] Wang B, Liu Y, Zhang YC, Han ZY, Hou JL, Chen S, et al. Assessment of causal effects of physical activity on the risk of osteoarthritis: A two-sample Mendelian randomization study. *BMC Med Genomics.* 2023;16(1):237. DOI: [10.1186/s12920-023-01681-x](https://doi.org/10.1186/s12920-023-01681-x)
- [11] Whitcomb DC, Buchner AM, Forsmark CE. AGA Clinical practice update on the epidemiology, evaluation, and management of exocrine pancreatic insufficiency: Expert review. *Gastroenterology.* 2023;165(5):1292–1. DOI: [10.1053/j.gastro.2023.07.007](https://doi.org/10.1053/j.gastro.2023.07.007)
- [12] Babinets LS, Shaihen OR, Homyn HO, Halabitska IM. [Specific aspects of clinical course in case of combination of chronic pancreatitis and concomitant viral hepatitis C.](#) *Wiad Lek.* 2019;72(4):595–99
- [13] Nilsson A, Bremander A. Measures of hip function and symptoms: Harris Hip Score (HHS), Hip Disability and Osteoarthritis Outcome Score (HOOS), Oxford Hip Score (OHS), Lequesne Index of Severity for Osteoarthritis of the Hip (LISOH), and American Academy of Orthopedic Surgeons (AAOS) Hip and Knee Questionnaire. *Arthritis Care Res.* 2011;63(Suppl 11):S200–S7. DOI: [10.1002/acr.20549](https://doi.org/10.1002/acr.20549)
- [14] Nawrot O. The biogenetical revolution of the Council of Europe – twenty years of the Convention on Human Rights and Biomedicine (Oviedo Convention). *Life Sci Soc Policy.* 2018;14:11. DOI: [10.1186/s40504-018-0073-2](https://doi.org/10.1186/s40504-018-0073-2)
- [15] Swain S, Sarmanova A, Coupland C, Doherty M, Zhang W. Comorbidities in osteoarthritis: A systematic review and meta-analysis of observational studies. *Arthritis Care Res.* 2020;72(7):991–1000. DOI: [10.1002/acr.24008](https://doi.org/10.1002/acr.24008)
- [16] King LK. Osteoarthritis and comorbidity: Time for action. *Osteoarthritis Cartilage.* 2023;31(4):423–24. DOI: [10.1016/j.joca.2023.01.007](https://doi.org/10.1016/j.joca.2023.01.007)

- [17] King LK, Marshall DA, Jones CA, Woodhouse LJ, Ravi B, Faris PD, et al. Are medical comorbidities contributing to the use of opioid analgesics in patients with knee osteoarthritis?. *Osteoarthritis Cartilage*. 2020;28(8):1030–37. DOI: [10.1016/j.joca.2020.04.012](https://doi.org/10.1016/j.joca.2020.04.012)
- [18] Diamond LE, Grant T, Uhlrich SD. Osteoarthritis year in review 2023: Biomechanics. *Osteoarthritis Cartilage*. 2024;32(2):138–47. DOI: [10.1016/j.joca.2023.11.015](https://doi.org/10.1016/j.joca.2023.11.015)
- [19] Mobasheri A, Thudium CS, Bay-Jensen AC, Maleitzke T, Geissler S, Duda GN, et al. Biomarkers for osteoarthritis: Current status and future prospects. *Best Pract Res Clin Rheumatol*. 2023;37(2):101852. DOI: [10.1016/j.berh.2023.101852](https://doi.org/10.1016/j.berh.2023.101852)
- [20] Sacitharan PK. Ageing and osteoarthritis. *Subcell Biochem*. 2019;91:123–59. DOI: [10.1007/978-981-13-3681-2_6](https://doi.org/10.1007/978-981-13-3681-2_6)
- [21] Kloppenburg M, Kroon FP, Blanco FJ, Doherty M, Dziedzic KS, Greibrokk E, et al. 2018 update of the EULAR recommendations for the management of hand osteoarthritis. *Ann Rheum Dis*. 2019;78(1):16–24. DOI: [10.1136/annrheumdis-2018-213826](https://doi.org/10.1136/annrheumdis-2018-213826)
- [22] Arruda AL, Hartley A, Katsoula G, Smith GD, Morris AP, Zeggini E. Genetic underpinning of the comorbidity between type 2 diabetes and osteoarthritis. *Am J Hum Genet*. 2023;110(8):1304–18. DOI: [10.1016/j.ajhg.2023.06.010](https://doi.org/10.1016/j.ajhg.2023.06.010)

Вплив екзокринної недостатності підшлункової залози на перебіг остеоартрозу за умов коморбідності

Ірина Галабіцька

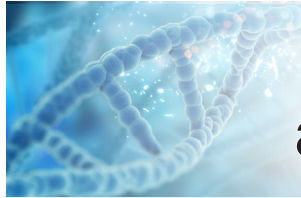
Кандидат медичних наук, асистент
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0002-9028-7230>

Лілія Бабінець

Доктор медичних наук, професор, завідувач кафедри
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0002-0560-1943>

Анотація. Взаємозв'язок між хронічними захворюваннями та остеоартрозом є звичним явищем, особливо серед людей похилого віку. Пацієнти з остеоартрозом потребують комплексного підходу, що включає співпрацю різних медичних спеціалістів, таких як лікарі загальної практики, ревматологи, ортопедичні хірурги, гастроентерологи та травматологи. Метою цього дослідження було вивчення впливу захворювань, пов'язаних з екзокринною недостатністю підшлункової залози, на перебіг первинного остеоартрозу в умовах коморбідності. Було проаналізовано 304 пацієнти з первинним остеоартрозом та екзокринною недостатністю підшлункової залози. Всіх пацієнтів було розподілено на п'ять груп залежно від типу супутньої патології. Досліджено, що у групі пацієнтів з чистою формою первинного остеоартрозу спостерігався статистично значимо полегшений перебіг захворювання за різними показниками, такими як рентгенологічна стадія остеоартрозу, функціональної недостатності суглобів, індекс Лекена, індекс нестероїдних протизапальних препаратів, порівняно з показниками у групах з іншими супутніми захворюваннями ($p < 0,05$). Це підтверджує значний вплив досліджуваної супутньої патології на перебіг первинного остеоартрозу. Під час проведення постхок-аналізу було визначено ранжування впливу коморбідних захворювань, що супроводжуються екзокринною недостатністю підшлункової залози, на клінічний перебіг первинного остеоартрозу за різними показниками, такими як рентгенологічна стадія остеоартрозу, функціональна недостатність суглобів, індекс Лекена, та індекс нестероїдних протизапальних препаратів. Результати ранжування: цукровий діабет 2-го типу > хронічний панкреатит > гепато-біліарні хвороби > гастро-дуоденальні хвороби ($p < 0,05$). Виявлено, що в групі пацієнтів з ізольованим первинним остеоартрозом була наявна легка екзокринна недостатність підшлункової залози за показником фекальної α -еластази. Також було встановлено ранжування впливу патологій, що супроводжуються екзокринною недостатністю підшлункової залози, на перебіг первинного остеоартрозу за рівнем фекальної α -еластази: хронічний панкреатит > цукровий діабет 2-го типу > гепато-біліарні хвороби > гастро-дуоденальні хвороби ($p < 0,05$). Результати роботи можуть бути використані у клінічній практиці лікарів різних спеціальностей: лікарі загальної практики, ревматологи, гастроентерологи

Ключові слова: суглобовий синдром; функціональна недостатність підшлункової залози; гастроентерологічні захворювання; цукровий діабет 2-го типу



Development and validation of a mathematical model for predicting the development of gastro-oesophageal reflux disease based on oesophagogastroduodenoscopy

Oleksandr Halushko*

Postgraduate Student
Volodymyr Vynnychenko Central Ukrainian State University
25000, 1 Shevchenko Str., Kropyvnytskyi, Ukraine
<https://orcid.org/0009-0009-0275-6542>

Yurii Hurtovyi

PhD in Physical and Mathematical Sciences, Associate Professor
Volodymyr Vynnychenko Central Ukrainian State University
25000, 1 Shevchenko Str., Kropyvnytskyi, Ukraine
<https://orcid.org/0000-0002-1499-7089>

Abstract. The purpose of this study was to identify a set of prognostic factors for the progression of gastro-oesophageal reflux disease for use in the development of a mathematical model for predicting this disease based on the results of oesophagogastroduodenoscopy. The study identified a range of prognostic factors for gastro-oesophageal reflux disease and a statistical method was employed to determine the level of their correlation with the development of the disease. The study found a link between certain clinical indicators and the occurrence of gastro-oesophageal reflux disease, which led to the formation of a set of prognostic factors for the progression of gastro-oesophageal reflux disease, including heartburn, frequent belching, regurgitation, damage to the mucous membrane of the oesophagus, stomach, duodenum, the presence of chronic gastroduodenitis, gastrointestinal dysfunction, bile reflux. In creating the mathematical prediction model, the logistic regression method was used to identify the correlation between the patient's clinical indicators and the occurrence of reflux disease and to determine the probability of its progression. To bring the clinical information in line with the statistical formula, it was assigned the values of independent variables, and the presence or absence of a particular indicator was coded using the binary number system. To test the developed model, recommendations were given to assess the statistical significance of the independent variables to determine its adequacy and to determine the predictive ability by testing on an independent sample of patients. The developed prognostic model is of great practical significance for patients, the healthcare industry, and the further development of the field, as it enables prompt detection of diseases and suitable prevention and treatment measures, increases the diagnostic potential of the industry, optimises the allocation of medical resources, and leverages machine learning and artificial intelligence capabilities based on the existing model

Keywords: heartburn; regurgitation; oesophageal mucosa; gastrointestinal tract; bile; logistic regression

★ INTRODUCTION

The need to develop a reliable model for predicting the development of gastro-oesophageal reflux disease arose due to problems associated with the late detection of the disease and, as a result, the complexity of its treatment. Gastro-oesophageal reflux disease (GORD) is an acute or chronic inflammation of the oesophagus (oesophagitis)

that develops as a result of the backflow of stomach contents into the oesophagus (reflux). The disease is accompanied by a range of symptoms, including heartburn, belching, heaviness and/or pain in the oesophagus when swallowing food or saliva, hiccups, a lump in the throat, and vomiting. Depending on the stage of GORD, its clinical signs

Suggested Citation:

Halushko O, Hurtovyi Yu. Development and validation of a mathematical model for predicting the development of gastro-oesophageal reflux disease based on oesophagogastroduodenoscopy. *Bull Med Biol Res.* 2024;6(1):15–23. DOI: 10.61751/bmbr/1.2024.15

*Corresponding author



change – from erosive changes in certain areas of the oesophagus at the first stage to the formation of ulcers, stricture, stenosis, and metaplasia of the oesophageal mucosa (degeneration of its epithelial cells) at the fourth stage. Apart from having a considerable impact on the quality of life (reduced ability to work, changes in the usual regime, and dietary restrictions), the progression of GORD can be a factor in many complications, the most serious of which is the development of a malignant tumour of the oesophagus.

Currently, there are several major problems associated with the prediction of GORD. Thus, the high variability of its symptoms and the lack of reliable clinical markers considerably complicate the prognostic process and affect its accuracy. T. Reva *et al.* [1], K.M. Chue *et al.* [2], S. Shinzaki *et al.* [3] investigated this issue. In these studies, the researchers found the dependence of GORD variants and concomitant lesions on the level of reflux acidity, established the usefulness of the Hill classification for predicting the development of this disease after laparoscopic sleeve gastrectomy, and assessed the significance of such prognostic factors as smoking, functional dyspepsia, hiatal hernia, and severe gastric atrophy. The effect of different types of bile on the risk of oesophageal mucosal damage can be considered a prognostic factor for the progression of GORD, but focusing on only one parameter, without considering other clinical characteristics of the patient, can lead to a decrease in the accuracy of the prognosis. The Hill classification of the gastro-oesophageal junction has shown a close relationship with the development of postoperative GORD, but it is not advisable to use it as a universal indicator for predicting the disease in other clinical situations. The same statement applies to smoking, functional dyspepsia, hiatal hernia, and severe gastric atrophy, as these risk factors have been considered in the context of predicting the progression of GORD after successful eradication of *Helicobacter pylori*, while their significance for other clinical cases has not been fully established. E.M. Wessels *et al.* [4] determined the risk of developing GORD after oral endoscopic myotomy. Thus, oral endoscopic myotomy as a risk factor for GORD can be considered as a prognostic factor for the progression of the disease, but only for the group of patients who are indicated for the treatment of achalasia.

When studying ways to predict the development of GORD, certain questions arise about the methods of clinical trials of patients. D. Armstrong *et al.* [5], S.P. Lee *et al.* [6] investigated these issues. In the study, the researchers used a survey to identify the differences between clinicians in their approach to initial investigations to detect and predict the progression of GORD – some doctors favoured the use of upper endoscopy, while others preferred oesophageal manometry and pH monitoring; the researchers also noted differences in the interpretation of endoscopic images of the gastro-oesophageal junction between observers with different levels of experience (expert endoscopists and trainees). S. Myasoyedov & S. Andreieshev [7], B. Shevchenko *et al.* [8] analysed the effectiveness of morphofunctional oesophagological monitoring and endoscopic ultrasound examination. The obtained results demonstrate the effectiveness of imaging methods due to their high information content and variability according to the individual clinical picture of the patient, but the

possibility of error in the interpretation of the results due to the subjective perception of the observer is still a problem.

The analysis of the studies revealed the lack of universal reliable prognostic factors and a single research method for the prognosis of GORD, and therefore the purpose of this study was to establish clinical indicators that can be used in combination as prognostic factors for the development of this disease. The main objectives of this study were to develop a mathematical model for predicting the development of GORD based on the identified prognostic indicators obtained by oesophagogastroduodenoscopy and to establish reliable methods for validating this model.

✦ MATERIALS AND METHODS

The creation of a mathematical model for predicting the progression of GORD was based on the use of clinical indicators that characterise the state of the gastrointestinal tract and have prognostic significance for the development of the disease, and the development of the most accurate method for identifying statistically significant correlations between these indicators and GORD.

The prognostically significant clinical indicators were identified by analysing the literature on the relevant topics, including the findings of theoretical and clinical studies on the prognosis, diagnostics, and treatment of GORD; the investigation of the profile of informativeness and reliability of oesophagogastroduodenoscopy as a method for collecting information on the clinical characteristics of the gastrointestinal tract of patients with GORD was based on the analysis of the technical characteristics of this method and the review of literature sources, including materials from clinical trials using it. The studies were searched for in PubMed, Web of Science, Google Scholar, and Scopus databases.

After clarifying the prognostically significant clinical indicators and determining the method of their obtaining, a mathematical model was developed to predict the progression of GORD. The first stage in building the model involved collecting clinical information from the patient, while the second involved statistical processing of the collected data. The patient's clinical information included a history and complaints to determine the presence of characteristic symptoms of GORD. Statistical processing was used to identify the correlation between the patient's clinical parameters and the development of reflux disease. The statistical method was chosen based on its ability to accommodate all identified clinical indicators, convert them into digital codes while maintaining clinical significance, and calculate the level of probability of disease occurrence or non-occurrence with maximum accuracy. Subsequently, the collected clinical information was coded for further analysis. The type of coding was chosen based on the statistical method chosen – logistic regression, regression analysis. In case of the logistic regression method, the dependent variable was reflux disease, while the independent variables were clinical data from the survey and endoscopic examination.

Assignment of parameters to clinical data and their coding according to the binary numbering system was as follows: GORD (p) – according to the results of the calculations, it would acquire one of two values: 0 – the disease is absent, 1 – the disease is present; the presence of risk factors for the progression of GORD (x_1, \dots, x_n) – 0 – absent, 1 – present. Considering these parameters, the development of

a mathematical model for predicting the development of GORD was based on the following formula:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_nx_n, \quad (1)$$

where p – the probability of the emergence of GORD; x_1, \dots, x_n – defined risk factors for the development of GORD; β_0 – a constant indicating the log odds of the development of reflux disease when all independent variables are equal to zero; β_1, β_n – coefficients reflecting the change in the log odds of developing reflux disease when the corresponding independent variable (x_1, \dots, x_n) changes by one, if, conditionally, all other indicators stay unchanged.

To determine the statistical adequacy of the developed mathematical model, the following indicators were considered: coefficient of determination (R-square), Akaike's information criterion (AIC), Bayesian information criterion (BIC), t-test, and Wald test. To determine the effectiveness of this model, the study employed validation methods – checking an independent sample of patients divided into a training and a test group, and cross-validation, which helped to determine the parameters of accuracy, sensitivity, specificity of the created model, and calculate the error of the developed model using ROC analysis.

The practical significance of this study was determined by analysing aspects of the clinical relevance of the developed model. These aspects included value for the patient, value for the healthcare industry, and value for the further development of the field.

RESULTS

The development of a mathematical model for predicting the progression of GORD was based on the relationship between real clinical data obtained during the interview and examination of the patients' gastrointestinal tract and the presence of GORD. Notably, it is crucial to define a set of indicators to create a model, as this will enable a more accurate prediction of the probability of the disease occurring and help to avoid false results. Therefore, when considering the degree of prognosticity of clinical data, it is necessary to determine the type of their connection with GORD (direct or indirect), to determine the specificity and to pay attention to other aspects that may affect the error in determining the prognosis.

The classic symptoms of GORD – heartburn, frequent belching, and regurgitation – are detected during the collection of complaints and anamnesis (heartburn, frequent belching) and endoscopic examination (regurgitation). Heartburn is directly related to the progression of GORD, as it can lead to an increase in acid production in the stomach and provoke inflammation of the mucous membrane, which will weaken the contraction of the muscles around the oesophagus, causing the opening of the floodgate through which the acidic contents of the stomach will return up into the oesophagus [9]. Regurgitation is the result of upper reflux, i.e., in the context of GORD, it is not the cause of its development, but a consequence [10]. Heartburn and regurgitation as indicators of GORD are highly sensitive, but not specific due to their association with other gastrointestinal problems: ulcerative colitis, intestinal dysfunction. Despite the high sensitivity of these symptoms, some patients with a confirmed diagnosis of

GORD who complain of chest pain do not have symptoms of heartburn or regurgitation.

Apart from visual examination of the oesophageal mucosa, the examination of the stomach and duodenum is informative. Damage to the oesophageal mucosa (erosion, ulceration) is a direct consequence of GORD and, at the same time, endoscopic signs of this disease [11]. Damage to the gastric mucosa affects the development of GORD in several ways: by increasing the production of gastric acid; by changes in gastric motility; by the development of ulcers or gastritis, which disrupt its protective barrier, reducing its effectiveness in preventing acid reflux into the oesophagus [12]. There are several mechanisms of influence of duodenal mucosa lesions on the development of GORD. The first one is triggered by inflammation, which can lead to relaxation of the lower oesophageal sphincter, causing acid from the stomach to enter the oesophagus (Fig. 1), while the second one is caused by changes in the balance of stomach acids, which can affect the motor activity of the stomach and disrupt the normal digestive process [13].

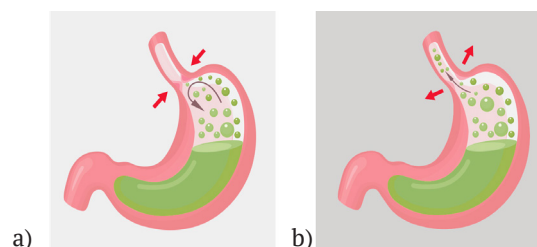


Figure 1. The mechanism of reflux during relaxation of the lower oesophageal sphincter

Notes: a) – sphincter is closed (normal); b) – sphincter is relaxed

Source: [14]

Thus, damage to the mucous membrane of the stomach and duodenum can be considered as a factor in the progression or exacerbation of GORD. Notably, gastroduodenitis, as an inflammatory process in the wall of the stomach and duodenum, can trigger several of the above mechanisms of gastric reflux, and its chronic form considerably increases the risk of developing GORD due to the prolonged irritating effect of bile on the oesophageal mucosa. Damage to the oesophageal mucosa is a more specific prognostic indicator of GORD than damage to the stomach and duodenum, but considering the presence of other factors that can lead to ulceration or erosion (e.g., thermal or chemical burns), the level of specificity cannot be considered sufficient to use it as the sole indicator of the probability of GORD progression.

Disorders of the gastrointestinal tract functioning are not specific to the progression of GORD, but in combination with the other clinical indicators mentioned above, they can more clearly predict the probability of progression or severity of this disease. Dysfunctions of the digestive system have several ways of influencing the progression of GORD. Gastritis and peptic ulcer disease can cause an increase in stomach acid production, which leads to its entry into the oesophagus [15]. Oesophageal sphincter dysfunction or achalasia causes a decrease in the tone of the sphincter, which is responsible for acid retention in the stomach [16]. Impaired peristalsis can lead to food

retention in the stomach, thus contributing to the development of GORD [17]. The direct impact of bile reflux on the progression of GORD is associated with the action of aggressive bile components that cause irritation and, with prolonged contact, inflammation of the oesophageal mucosa. The indirect effect is exerted through the release of bile into the stomach, which provokes an increase in the acidity of the gastric contents and damage to the barrier function of the lower oesophageal sphincter [18]. The presence of bile reflux may indicate certain problems of the gastrointestinal tract, and therefore, despite the low specificity of this indicator for the progression of GORD, its use as a prognostic factor is important, especially in combination with other clinical characteristics.

The effect of each type of bile on the development of GORD is related to its composition. Although the main components are bile acids, additional substances necessary for the normal digestive process may be included at different stages of the pathway. The principal components of bile produced by the liver are water, bile acids, proteins, fats, and electrolytes. When entering the biliary tract, mucus is added to these components, which provides additional binding of bile acids and protects the mucous membranes from erosion. In the gallbladder, bile is stored, concentrated, and fat-soluble substances are added to its composition for effective fat digestion [19]. Thus, when bile reflux occurs, the most aggressive irritation to the oesophageal mucosa is caused by bile that enters it from the gallbladder. Therefore, it can be assumed that in case of bile reflux, this type of bile is an additional indicator of GORD. Thus, to create a model for predicting the progression of GORD, indicators were selected that, in combination, allow the most accurate prediction of the probability of the disease. These indicators include heartburn, frequent belching, regurgitation, damage to the mucous membrane of the oesophagus, stomach, duodenum, chronic gastroduodenitis, gastrointestinal tract dysfunction, bile reflux (especially if bile enters the oesophagus from the gallbladder).

An important aspect that determines the reliability of a prognostic model is the choice of informative and accurate methods of patient examination. Apart from the symptom of heartburn, which is determined by the results of collecting complaints and patient history, other indicators of GORD progression are detected using instrumental imaging methods. The method of oesophagogastroduodenoscopy has shown high efficiency in the diagnosis of lesions of the mucous membranes of the gastrointestinal tract, which allows detecting endoscopic signs of GORD, including the type of damage (erosion, ulcer) and its volume. The informative and reliable nature of this method is ensured by a wide scope of its technical capabilities: the flexible design of the endoscopic tube allows the specialist to easily manipulate it during the passage through the internal organs; The optical system provides access to a clear image of the throat, oesophagus, stomach, and duodenum, which is displayed on the doctor's screen; the presence of channels for instruments allows for biopsies or other manipulations during the examination; the air supply function is used when it is necessary to expand the organs to facilitate the examination; thanks to the built-in video camera, images of the cavities of the examined organs in the format of photo or video materials can be saved for further

analysis of the examination data [20, 21]. When analysing clinical trials on the factors of development, diagnosis, and treatment of GORD, it was found that oesophagogastroduodenoscopy was used in many of them as a method of detecting the key endoscopic signs of the disease [22-24]. An additional advantage of this method is to resolve the issue of the possibility of misinterpretation of the results of the endoscopic examination by the observer, depending on their experience or other subjective factors, which is the possibility of video recording the results of the procedure and their repeated analysis with the involvement of several specialists.

When creating a mathematical model for predicting the progression of GORD, the principle of logistic relationships between the patient's clinical parameters and the probability of the disease occurrence was used. The accuracy and validity of this model is achieved through statistical analysis methods to process real clinical data collected from the survey and video oesophagogastroduodenoscopy. This approach makes it possible to identify and consider clinical characteristics and pathological changes in the digestive tract that are essential for predicting the progression of GORD. The model for predicting the progression of GORD is based on obtaining clinical information from the patient, including the collection of complaints and patient history, which aims to establish the presence of the characteristic symptoms of GORD – heartburn and frequent belching, and endoscopic examination results to identify lesions of the mucous membrane of the oesophagus, stomach, duodenum (erosion, ulcers), and to determine the presence of sphincter dysfunction (regurgitation), and statistical processing of the data obtained.

To improve the understanding of the principle of developing a mathematical model for predicting GORD, it is worth considering an example using the logistic regression method, as its principle allows determining the correlation between the patient's clinical parameters and the development of this disease. In this case, according to Equation 1, the clinical data of the survey and endoscopic examination will acquire the values of independent variables x_1-x_9 , while their coding according to the binary counting system will have the following form: the presence of heartburn complaints, frequent belching (x_1, x_2) – 0 – complaints absent, 1 – complaints present; lesions of the mucous membrane of the oesophagus, stomach, duodenum (x_3, x_4, x_5) – 0 – lesions absent, 1 – lesions present; sphincter disorders (regurgitation) (x_6) – 0 – disorders absent, 1 – disorders present; chronic gastroduodenitis (x_7) – 0 – disease absent, 1 – disease present; gastrointestinal tract disorders (x_8) – 0 – disorders absent, 1 – disorders present; bile reflux (x_9) – 0 – disorders absent, 1 – disorders present. Converting the Equation (1) in such a way as to calculate the probability of occurrence of the disease under study (p), the mathematical model for predicting the progression of GORD based on logistic regression will be as follows (2):

$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_9 x_9)}} \quad (2)$$

where p – the probability of GORD emergence; x_1 – the presence of heartburn complaints; x_2 – the presence of frequent belching complaints; x_3 – the presence of damage to the oesophageal mucosa; x_4 – the presence of damage to

the stomach mucosa; x_5 – the indicator of damage to the oesophageal mucosa; x_6 – the indicator of sphincter dysfunction (regurgitation); x_7 – the indicator of chronic gastro-duodenitis; x_8 – the indicator of gastrointestinal tract dysfunction; x_9 – the indicator of bile reflux; β_0 – a constant indicating the log odds of developing reflux disease when all independent variables are zero; β_1 - β_9 – coefficients reflecting the change in log odds of developing reflux disease when the corresponding independent variable changes (x_1 - x_9) per unit, if, conditionally, all other indicators stay unchanged; e – the Euler number, approximately equal to 2.71828.

In this case, the graphical representation of the results of assessing the probability of GORD progression using the proposed mathematical model will be represented by a logistic curve (Fig. 2).

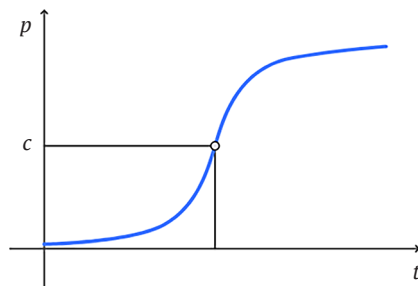


Figure 2. Graphical representation of the probability of GORD progression represented by a logistic curve

Notes: p is the probability of an event occurring (progression of GORD); c is the point after which the p function increases most rapidly (the probability of the disease progression increases); t is time (the study period)

Source: [25]

An increase in the value of the dependent variable means that an increase in the value of the corresponding independent variable is correlated with an increase in the chances of GORD progression. If, for instance, x_3 acquires a value of one, then the presence of damage to the mucous membrane of the oesophagus increases the risk of this disease. If the dependent variable decreases in response to an increase in the independent variable, it means that there is no association between a certain clinical indicator and the development of the disease. However, when developing the proposed mathematical model, clinical indicators were selected based on their direct or indirect association with the risk of GORD, and therefore the dependent variable is positively correlated with all independent variables. It is important to assess the overall adequacy of the developed mathematical model. For this, it is necessary to pay attention to the level of dependence of the dependent variable variation on the independent variables variation, which is determined based on the coefficient of determination (R-squared), the influence of out-of-sample variables on the model error – based on the AIC, the quality of the model – based on the balance between its accuracy and complexity BIC, and the statistical significance of independent variables – based on the t-test or Wald test.

It is vital to determine the accuracy and predictive ability of the mathematical model for predicting the progression of GORD by means of its validation. This stage is

crucial, as the created model has a concrete practical significance and is aimed at performing a responsible task in clinical practice. Therefore, to determine its predictive capability, it is necessary to conduct the necessary tests under conditions that will help to critically assess the advantages and identify possible disadvantages. For this, it is recommended to conduct a clinical trial with an independent sample of patients, dividing them into training and test groups, or through cross-validation. Based on the test sample, one can estimate the accuracy, sensitivity, and specificity parameters of the created model and conduct a ROC analysis by calculating the area under the error curve. The key criterion for the development of this model was its suitability for use in clinical practice. By defining a set of prognostic indicators, establishing the optimised method for their detection and applying relevant statistical methods for processing clinical information, compliance with the set criterion was achieved and a mathematical model was created that allows identifying patients at high risk of GORD progression before it occurs or before the development of a more severe degree of severity (erosive form or Barrett's syndrome).

First of all, this model is useful for patients, as it can accommodate their individual clinical characteristics and provide results promptly and with high accuracy. This helps to expand access to the procedure, reduce diagnostic time, and determine the treatment strategy depending on the results. Thus, the use of a mathematical model to predict the progression of GORD can affect the effectiveness of therapy for patients in different groups as follows: patients at risk of GORD progression will be able to avoid the effects of the disease by following the doctor's recommendations regarding the adjustment of their diet and lifestyle; patients with a promptly diagnosed disease will be able to increase the chance of successful medical treatment, reduce the risk of complications, and get the opportunity to regularly monitor its course; patients with a diagnosed severe reflux disease will be able to receive an assessment of the risks and, according to the treatment plan developed according to them, undergo the necessary procedures, which may include surgical procedures. The developed mathematical method for predicting GORD is of medical and economic significance for the healthcare system. Based on the principles of evidence-based and personalised medicine, this method can increase the diagnostic potential of gastroenterology and improve public health by being used during routine or unscheduled examinations of patients with problems or even minor complaints related to the functioning of the digestive tract. At the same time, improving the diagnostic potential of the industry will help optimise the allocation of medical and economic resources, focusing on patients who need them most and avoiding the cost of unnecessary procedures for patients who are not at risk of developing reflux disease.

It is also essential to evaluate the role of the developed model for the further development and improvement of diagnostic systems in various healthcare sectors. The area of modelling systems for predicting the development or assessing the severity of various diseases or pathological conditions, apart from its serious prospects, poses a range of significant challenges to the medical industry. To implement and use such models correctly in the healthcare

system, the following tasks need to be addressed: technical – to ensure high quality data, legal – to protect patient confidentiality, organisational – to develop standards and protocols for the use and interpretation of modelling results, educational – to ensure proper training of healthcare professionals. At the same time, the process of mathematical processing of clinical data opens wide opportunities for machine learning and artificial intelligence, which, apart from predicting the risks of disease progression, will allow for diagnosis, patient classification, determining the most effective treatment strategy and monitoring the patient's condition throughout the entire therapy process. Considering the above prospects and opportunities, mathematical modelling using the most advanced information technology systems still cannot be considered as an alternative to the work of doctors. These technologies primarily serve as a tool used by a specialist to achieve results more accurately, reliably, and quickly. Therefore, the mathematical model for predicting the progression of GORD was developed to solve the problems of untimely detection of the disease and improve the overall epidemiological situation with gastroenterological diseases.

◆ DISCUSSION

Analysing the findings obtained, the key aspects can be highlighted that were important in developing a mathematical model for predicting the progression of GORD. The medical component was critical for the result, which lied in selecting reliable prognostic factors among all clinical indicators that could be determined during the interview and physical, laboratory, and instrumental examinations. In studying the level of influence of these indicators, it was found that the close relationship between the digestive tract organs does not allow considering a certain clinical sign as the only indicator of predicting the progression of GORD due to the lack of sufficient specificity. Therefore, to improve the prognostic ability of the developed model, a set of clinical signs of the patient was formed, which had a direct or indirect impact on the development of reflux disease and included symptoms (heartburn, frequent belching, regurgitation), damage to the internal walls of organs (mucous membranes of the oesophagus, stomach, duodenum), gastrointestinal tract dysfunction (bile reflux and other disorders), and the presence of chronic gastroenterological diseases (chronic gastroduodenitis). M.E. Hossain *et al.* [26] described an approach to finding possible predictors of disease prognosis based on the use of electronic health data in a comprehensive literature review. The researchers investigated the significance of electronic data for use in predicting the development of diseases and found high accuracy of some modelling approaches developed based on such sources of medical information. The researchers also emphasised the viability and informativeness of the developed models, which were involved in the clinical process and showed promising results during operation. Considering the researchers' findings in the context of the present study, since the search for clinical indicators for building a model for predicting the progression of GORD was also carried out based on an analysis of materials on the relevant subject from previously published scientific sources, the effectiveness of the proposed approach can be confirmed.

When developing a model that contains several independent variables (clinical signs), attention should be paid to ways to optimise the model so that duration and resource consumption do not affect the overall benefit of its operation. It was possible to optimise the model in terms of procedure time and use of diagnostic equipment due to the choice of the method of instrumental examination – oesophagogastroduodenoscopy, as this procedure allows detecting all the listed clinical signs during one session using one device. The detection of heartburn and frequent burping symptoms occurs when collecting complaints and patient history during a consultation with a doctor and does not require additional equipment. H. Xu *et al.* [27] considered a comparable principle of optimising the model for diagnosing coronary heart disease. Based on a retrospective multicentre study, researchers identified eight significant risk factors, including demographic factors, clinical signs, and laboratory markers. The model was optimised by using standard research methods for determining cardiac disorders that do not require additional time or material resources. Generally, the approach of using standardised laboratory and instrumental research methods is most often used for optimisation in the disease progression prediction models [28-30].

A major step in creating the model was to choose a method of statistical processing of the collected data. The logistic regression used as an example demonstrated the possibility of quantifying the impact of each of the prognostic factors on the risk of GORD progression. This is because, despite its versatility, this method makes it possible to encrypt medical information in such a way that the correct results are obtained during the calculation. Thus, the probability of the disease progression is determined not only by the presence of a certain number of clinical indicators (independent variables), but also by the level of their prognostic significance (the coefficient reflecting the change in the log odds of developing reflux disease when the corresponding independent variable changes by one). Thus, this method makes it possible to identify the significance of prognostic indicators and assess the level of their interaction with the occurrence of the disease. Y. Deng *et al.* [31] employed a combination of machine learning and logistic regression to create their model to predict the risk of carotid plaques in adults with fatty liver disease. Based on the analysis of data from a population-based cross-sectional study, the researchers selected 5 independent prognostic factors for the risk of carotid plaques from 27 clinical parameters. The use of a combination of statistical methods and advanced information technology systems has revealed a higher predictive efficiency of the created model compared to the use of logistic regression and machine learning algorithms separately. In the context of the objectives of the present study, the evidence-based approach to the selection of predictors of prognosis and statistical processing of the results provided a prominent level of prognostic significance of the developed model, which makes it possible to apply it in clinical practice. However, to increase productivity, it is worth considering the possibility of using machine learning or artificial intelligence in combination with the statistical method, having worked out in advance the legal, organisational, and technical support for this process.

The final stage in the development of a predictive model is to assess its adequacy through validation. Since this model was created for further use in clinical practice, the proposed method of validation included testing the statistical significance and predictive ability on an independent sample of patients. E.W. Steyerberg & Y. Vergouwe [32] evidentially confirmed this approach, having investigated the problematic issues of models for clinical prognosis. The researchers proposed steps to improve them, including the development and validation process. The researchers also proved the significance of testing the prognostic model according to two criteria: adequacy assessment, which is to determine the level of accuracy of the statistical method of processing the results, and effectiveness, which is carried out directly in clinical settings with an independent sample of patients.

Generally, when analysing the development of mathematical models for predicting the development or severity of diseases, the main criteria and vector followed by developers are evidence and personalisation. That is why research is currently underway in many areas of medicine to revise established diagnostic procedures due to limited information content, difficulty of interpretation, risk or discomfort for the patient, long waiting times, or other characteristic signs of obsolescence. Thus, the expediency of replacing some radiography methods with magnetic resonance imaging or computed tomography, liver function tests with ultrasound diagnostics, computed tomography and endoscopic retrograde cholangiopancreatography, and the Mantoux test with photofluorography was covered [33-35]. In the present study, when choosing a method for collecting clinical information, attention was also paid to the informativeness, accuracy, and speed of obtaining clinical information. Therefore, among endoscopic methods, the choice was between oesophagogastroduodenoscopy and capsule endoscopy. The advantage of capsule endoscopy was the absence of discomfort for the patient, but the disadvantages included:

- ♦ the procedure duration from 8 to 10 hours, depending on the duration of the capsule's natural movement through the digestive tract;
- ♦ limited use for patients with intestinal obstruction, perforation of the digestive system, swallowing disorders, motor disorders of the oesophagus or stomach.

The disadvantage of oesophagogastroduodenoscopy was the relative discomfort for the patient associated with the specific mechanics of the procedure, while the advantages were informativeness, speed, and the possibility of using it in cases where capsule endoscopy is contraindicated. Despite the accuracy of the developed model, which is ensured by the use of a set of clinical indicators that have an established relationship with the development of GORD, certain questions persist due to the fact that the indices studied separately have a low level of specificity for predicting this disease. Summarising the analysis of the results, it can be concluded that mathematical modelling of the risk of reflux disease progression is a reliable tool in clinical gastroenterology for the prompt detection and effective implementation of measures for the prevention and treatment of this disease.

◆ REFERENCES

- [1] Reva T, Reva V, Trefanenko I, Shumko H, Gaidichuk V. Variants of gastroesophageal reflux disease depending on the type of reflux. *Ukr J Med Biol Sport.* 2022;7(1):171–76. DOI: [10.26693/jmbs07.01.171](https://doi.org/10.26693/jmbs07.01.171)

◆ CONCLUSIONS

The creation of a mathematical model for predicting the progression of GORD was based on the identification of clinical indicators that can be used as prognostic factors, the substantiation of the choice of clinical research method for identifying these indicators, and the choice of the optimised method for processing clinical information.

A review of the relevant literature revealed links between certain clinical signs and the progression of GORD. The analysis of these relationships helped to identify prognostic factors for the development of the disease, including heartburn, frequent belching, regurgitation, damage to the mucous membrane of the oesophagus, stomach, duodenum, chronic gastroduodenitis, gastrointestinal dysfunction, and bile reflux. Oesophagogastroduodenoscopy proved to be the most informative method of detecting these risk factors, the technical characteristics of which allow for the informativeness and speed of obtaining the necessary clinical parameters. The logistic regression method was used to identify the correlation between the patient's clinical parameters and the development of reflux disease. Its principle was to encode clinical information for the mathematical calculation of the probability of a disease occurring. According to the criteria of the logistic equation, all clinical parameters were assigned the values of the corresponding variables: the dependent variable is the probability of GORD progression, independent variables are prognostic factors for the progression of GORD coded in binary.

Recommendations for model validation include assessment of the overall model adequacy – statistical significance, and validation – predictive ability determined based on a clinical trial with an independent sample. The developed prognostic model is of practical significance for patients, as it allows them to identify the risks of developing the disease in time and take relevant preventive or therapeutic measures to thwart the consequences of the disease; for the healthcare system, increasing the diagnostic potential of gastroenterology and optimising the allocation of labour and economic resources; for further development and improvement of the diagnostic area, using the capabilities of the most advanced information technology systems – machine learning and artificial intelligence. The practical significance of the developed model allows recommending its use in the clinical practice of gastroenterologists.

One of the limitations of the present study was the low level of specificity of the identified prognostic factors separately from each other, which may slightly affect the accuracy of the developed model. Therefore, the key vector for further research in this area may be the search for indicators with a higher level of specificity, e.g., laboratory or genetic markers of GORD.

◆ ACKNOWLEDGEMENTS

None.

◆ CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

- [2] Chue KM, Goh DWX, Chua CME, Toh BC, Ong LWL, Wong WK, et al. The Hill's classification is useful to predict the development of postoperative gastroesophageal reflux disease and erosive esophagitis after laparoscopic sleeve gastrectomy. *J Gastrointest Surg.* 2022;26(6):1162–70. DOI: [10.1007/s11605-022-05324-x](https://doi.org/10.1007/s11605-022-05324-x)
- [3] Shinozaki S, Osawa H, Hayashi Y, Miura Y, Yano T, Lefor AK, Yamamoto H. Predictors and timing for the development of symptomatic gastroesophageal reflux disease after successful *Helicobacter pylori* eradication therapy. *Scand J Gastroenterol.* 2021;57(1):16–21. DOI: [10.1080/00365521.2021.1975310](https://doi.org/10.1080/00365521.2021.1975310)
- [4] Wessels EM, Masclee GMC, Bastiaansen BAJ, Fockens P, Bredenoord AJ. Incidence and risk factors of reflux esophagitis after peroral endoscopic myotomy. *Neurogastroenterol Motil.* 2024 Apr 8;36(6):e14794. DOI: [10.1111/nmo.14794](https://doi.org/10.1111/nmo.14794)
- [5] Armstrong D, Hungin AP, Kahrilas PJ, Sifrim D, Sinclair P, Vaezi MF, Sharma P. Knowledge gaps in the management of refractory reflux-like symptoms: Healthcare provider survey. *Neurogastroenterol Motil.* 2022;34(10):e14387. DOI: [10.1111/nmo.14387](https://doi.org/10.1111/nmo.14387)
- [6] Lee SP, Kae SH, Jang HJ, Koh DH, Jung ES. Inter-observer variability of experts and trainees for the diagnosis of reflux esophagitis: Comparison of linked color imaging, blue laser imaging, and white light imaging. *J Dig Dis.* 2021;22(7):425–32. DOI: [10.1111/1751-2980.13023](https://doi.org/10.1111/1751-2980.13023)
- [7] Myasoyedov S, Andreieshev S. Morpho-functional monitoring of the esophagus status as the base for the dispenser observation in the patients with achalasia of cardia after surgical esophagocardiomyotomy. *Clin Surg.* 2021;88(9–10):16–20. DOI: [10.26779/2522-1396.2021.9-10.16](https://doi.org/10.26779/2522-1396.2021.9-10.16)
- [8] Shevchenko B, Babii O, Prolom N, Titova M, Tarabarov S, Ushchina S. The role of endoscopic ultrasound in assessment of physiological cardia insufficiency during diagnosis of hiatal hernia. *Gastroenterol.* 2024;58(1):50–56. DOI: [10.22141/2308-2097.58.1.2024.587](https://doi.org/10.22141/2308-2097.58.1.2024.587)
- [9] Savarino E, Marabotto E, Savarino V. Recent insights on functional heartburn and reflux hypersensitivity. *Cur Opin Gastroenterol.* 2022;38(4):417–22. DOI: [10.1097/mog.0000000000000846](https://doi.org/10.1097/mog.0000000000000846)
- [10] Di Mario F, Crafa P, Franzoni L, Tursi A, Brandimarte G, Russo M, et al. A comparison of different symptomatic reflux esophagitis treatments: A real-world study. *Adv Clin Exp Med.* 2023;32(9):1075–80. DOI: [10.17219/acem/171001](https://doi.org/10.17219/acem/171001)
- [11] HajHosseini P, Takaloozadeh M. An isotropic hyperelastic model of esophagus tissue layers along with three-dimensional simulation of esophageal peristaltic behavior. *J Bioeng Res.* 2019;1(2):12–27. DOI: [10.22034/JBR.2019.189018.1009](https://doi.org/10.22034/JBR.2019.189018.1009)
- [12] Miftahussurur M, Waskito LA, Syam AF, Nusi IA, Wibawa IDN, Rezkitha YAA, et al. Serum pepsinogen level as a biomarker for atrophy, reflux esophagitis, and gastric cancer screening in Indonesia. *J Res Med Sci.* 2022;27(1):90. DOI: [10.4103/jrms.jrms_983_21](https://doi.org/10.4103/jrms.jrms_983_21)
- [13] Wang M, Lou E, Xue Z. The role of bile acid in intestinal metaplasia. *Front Physiol.* 2023;14:1115250. DOI: [10.3389/fphys.2023.1115250](https://doi.org/10.3389/fphys.2023.1115250)
- [14] Causes and symptoms of esophagitis [Internet]. [cited 2023 Dec 1]. Available from: <https://medikom.ua/simptom-yehzofagita/>
- [15] Yalaki S, Pulat H, Ilhan A. Localization of *Helicobacter pylori* gastritis and the relation of existing histopathological features with reflux esophagitis. *Scand J Gastroenterol.* 2020;55(1):27–33. DOI: [10.1080/00365521.2019.1701071](https://doi.org/10.1080/00365521.2019.1701071)
- [16] Dunn CP, Wu J, Gallagher SP, Putnam LR, Bildzukewicz NA, Lipham JC. Understanding the GERD barrier. *J Clin Gastroenterol.* 2021;55(6):459–68. DOI: [10.1097/mcg.0000000000001547](https://doi.org/10.1097/mcg.0000000000001547)
- [17] Hu ZW, Wang ZG, Wu JM, Tian SR, Zhang Y, Zhan XL, et al. Relationship between the severity of reflux esophagitis and the esophageal motility features on high resolution manometry. *Chin Med J.* 2017;97(42):3306–11. DOI: [10.3760/cma.j.issn.0376-2491.2017.42.007](https://doi.org/10.3760/cma.j.issn.0376-2491.2017.42.007)
- [18] Chen L, Zhu G, She L, Ding Y, Yang C, Zhu F. Analysis of risk factors and establishment of a prediction model for endoscopic primary bile reflux: A single-center retrospective study. *Front Med.* 2021;8:758771. DOI: [10.3389/fmed.2021.758771](https://doi.org/10.3389/fmed.2021.758771)
- [19] Qu X, Shi Y. Bile reflux and bile acids in the progression of gastric intestinal metaplasia. *Chin Med J.* 2022;135(14):1664–72. DOI: [10.1097/CM9.0000000000002290](https://doi.org/10.1097/CM9.0000000000002290)
- [20] Cohen J, Safdi MA, Deal SE, Baron TH, Chak A, Hoffman B, et al. Quality indicators for esophagogastroduodenoscopy. *Am J Gastroenterol.* 2006;101(4):886–91. DOI: [10.1111/j.1572-0241.2006.00676.x](https://doi.org/10.1111/j.1572-0241.2006.00676.x)
- [21] Barret M, Chaussade S, Boustière C, Canard JM, Schott AM, Ponchon T, et al. Diagnostic yield of esophagogastroduodenoscopy in France. *Clin Res Hepatol Gastroenterol.* 2021;45(4):101540. DOI: [10.1016/j.clinre.2020.08.015](https://doi.org/10.1016/j.clinre.2020.08.015)
- [22] Martín-Marcos I, Fernández-Morte N, Balsategui-Martín M, Ortiz-Cantero A, Bermúdez-Ampudia C, López-Picado A, et al. Evaluation of pharyngeal lidocaine anesthesia for esophagogastroduodenoscopy: Double-blind randomized control trial. *Dig Endosc.* 2021;34(4):808–15. DOI: [10.1111/den.14168](https://doi.org/10.1111/den.14168)
- [23] Suda T, Shirota Y, Takimoto H, Tsukada Y, Takishita K, Nadamura T, et al. Image quality of abdominal ultrasonography after esophagogastroduodenoscopy is preserved by using carbon dioxide insufflation: A non-inferiority test in the same subject. *PLoS One.* 2022;17(9):e0275257. DOI: [10.1371/journal.pone.0275257](https://doi.org/10.1371/journal.pone.0275257)
- [24] Bilder HG, Soccini C, Lasa JS, Zubiaurre I. Impact of time to esophagogastroduodenoscopy in patients with nonvariceal upper gastrointestinal bleeding: A systematic review and meta-analysis. *J Gastroenterol Mexico.* 2022;87(3):320–29. DOI: [10.1016/j.rgmxen.2021.11.010](https://doi.org/10.1016/j.rgmxen.2021.11.010)
- [25] What are logistic models used for? [Internet]. [cited 2023 Dec 1]. Available from: <https://www.houseofmath.com/uk/encyclopedia/funktsiyi/matematychni-modeli/typy-modeley/dlya-choho-vykorystovuyutsya-lohistychni-modeli>

- [26] Hossain ME, Khan A, Moni MA, Uddin S. Use of electronic health data for disease prediction: A comprehensive literature review. *IEEE/ACM Trans Comput Biol Bioinform.* 2021;18(2):745–58. DOI: [10.1109/tcbb.2019.2937862](https://doi.org/10.1109/tcbb.2019.2937862)
- [27] Xu H, Duan Z, Miao C, Geng S, Jin Y. Development of a diagnosis model for coronary artery disease. *Ind Heart J.* 2017;69(5):634–39. DOI: [10.1016/j.ihj.2017.02.022](https://doi.org/10.1016/j.ihj.2017.02.022)
- [28] Cui Z, Liu JX, Gao YL, Zhu R, Yuan SS. LncRNA-disease associations prediction using bipartite local model with nearest profile-based association inferring. *IEEE J Biomed Health Inform.* 2020;24(5):1519–27. DOI: [10.1109/jbhi.2019.2937827](https://doi.org/10.1109/jbhi.2019.2937827)
- [29] Holcomb KM, Staples JE, Nett RJ, Beard CB, Petersen LR, Benjamin SG, et al. Multi-model prediction of West Nile virus neuroinvasive disease with machine learning for identification of important regional climatic drivers. *GeoHealth.* 2023;7(11):e2023GH000906. DOI: [10.1029/2023GH000906](https://doi.org/10.1029/2023GH000906)
- [30] Hao M, Huang X, Liu X, Fang X, Li H, Lv L, et al. Novel model predicts diastolic cardiac dysfunction in type 2 diabetes. *Ann Med.* 2023;55(1):766–77. DOI: [10.1080/07853890.2023.2180154](https://doi.org/10.1080/07853890.2023.2180154)
- [31] Deng Y, Ma Y, Fu J, Wang X, Yu C, Lv J, et al. Combinatorial use of machine learning and logistic regression for predicting carotid plaque risk among 5.4 million adults with fatty liver disease receiving health check-ups: Population-based cross-sectional study. *JMIR Public Health Surveill.* 2023;9:e47095. DOI: [10.2196/47095](https://doi.org/10.2196/47095)
- [32] Steyerberg EW, Vergouwe Y. Towards better clinical prediction models: Seven steps for development and an ABCD for validation. *Eur Heart J.* 2014;35(29):1925–31. DOI: [10.1093/eurheartj/ehu207](https://doi.org/10.1093/eurheartj/ehu207)
- [33] Ahlawat S. Current state-of-the-art imaging techniques in the domain of whole-body MRI and its advantages over other whole-body PET in different musculoskeletal diseases. *Eur Radiol.* 2023;33(12):8573–75. DOI: [10.1007/s00330-023-09883-8](https://doi.org/10.1007/s00330-023-09883-8)
- [34] Rastogi A. Changing role of histopathology in the diagnosis and management of hepatocellular carcinoma. *World J Gastroenterol.* 2018;24(35):4000–13. DOI: [10.3748/wjg.v24.i35.4000](https://doi.org/10.3748/wjg.v24.i35.4000)
- [35] Tandon A, Tandon S. [Fallacies of mantoux in the diagnosis of latent tuberculosis.](https://doi.org/10.1007/s00330-023-09883-8) *J Assoc Physic India.* 2022;70(12):94–95.

Розробка та валідація математичної моделі для прогнозування розвитку рефлюкс-езофагіту на основі даних відеоезофагогастроуденоскопії

Олександр Галушко

Аспірант

Центральноукраїнський державний університет імені Володимира Винниченка
25000, вул. Шевченка, 1, м. Кропивницький, Україна
<https://orcid.org/0009-0009-0275-6542>

Юрій Гуртовий

Кандидат фізико-математичних наук, доцент

Центральноукраїнський державний університет імені Володимира Винниченка
25000, вул. Шевченка, 1, м. Кропивницький, Україна
<https://orcid.org/0000-0002-1499-7089>

Анотація. Дослідження мало на меті визначити комплекс прогностичних факторів розвитку рефлюкс-езофагіту для використання їх в розробці математичної моделі прогнозування даного захворювання на основі результатів відеоезофагогастроуденоскопії. Під час його проведення було встановлено низку прогностичних факторів рефлюкс-езофагіту та задіяно статистичний метод для встановлення рівня їх кореляції із розвитком хвороби. За результатами дослідження було виявлено зв'язок між певними клінічними показниками та виникненням рефлюкс-езофагіту, на основі чого сформовано комплекс прогностичних факторів розвитку гастроєзофагеальної рефлюксної хвороби, який включав: печію, часті відрижки, регургітацію, ушкодження слизової оболонки стравоходу, шлунку, дванадцятипалої кишки, наявність хронічного гастродуоденіту, порушення функціонування шлунково-кишкового тракту, жовчний рефлюкс. В створенні математичної моделі прогнозування було використано метод логістичної регресії, який застосовувався для виявлення кореляції між клінічними показниками пацієнта й фактом виникнення рефлюксної хвороби та визначення ймовірності її розвитку. Для приведення клінічної інформації у відповідність статистичній формулі їй надавалось значення незалежних змінних, а наявність чи відсутність певного показника кодувалось за двійковою системою числення. Для перевірки розробленої моделі приводились рекомендації із оцінки статистичної значущості незалежних змінних для визначення її адекватності, та визначення предиктивної здатності шляхом випробування на незалежній вибірці пацієнтів. Розроблена прогностична модель має важливе практичне значення для пацієнтів, галузі охорони здоров'я та подальшого розвитку напрямку, так як дозволяє вчасно виявити захворювання і вжити відповідних заходів з профілактики та лікування, підвищити діагностичний потенціал галузі, оптимізувати розподіл медичних ресурсів та задіювати можливості машинного навчання й штучного інтелекту на основі існуючої моделі

Ключові слова: печія; регургітація; слизова оболонка стравоходу; шлунково-кишковий тракт; жовч; логістична регресія



Effect of pelvic tilt on changing the centre of rotation of the hip joint in preoperative planning

Oleksandr Zubkov*

Postgraduate Student

Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine

01601, 27 Bulvarno-Kudriavska Str., Kyiv, Ukraine

<https://orcid.org/0009-0002-6763-5062>

Victor Torchynskyi

Doctor of Medical Sciences, Senior Researcher

Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine

01601, 27 Bulvarno-Kudriavska Str., Kyiv, Ukraine

<https://orcid.org/0000-0003-4818-9511>

Abstract. The growing number of hip replacements associated with an ageing population requires more accurate and efficient methods of planning operations to ensure the success of interventions and minimise the risk of complications. The study aimed to demonstrate how changes in the pelvic angle affect the accurate determination of the centre of rotation of the hip joint. The study used dry pelvic and femoral bones with a 4 mm diameter implanted steel ball in the femoral head for modelling. X-rays were taken using a PLX 140 X-ray machine to record the displacement of the centre of rotation. The study confirmed the hypothesis that a change in the pelvic angle leads to a shift in the centre of rotation of the hip joint. This displacement requires attention during preoperative planning, as it can affect the choice and placement of the endoprosthesis. The study found that a high pelvic angle makes it difficult to fit a hip prosthesis, increasing the risk of prosthesis wear and dislocation. This requires an individualised approach to each patient, the use of special implants and postoperative monitoring. It is necessary to assess the anteversion and inclusion of the prosthesis, adjust the implantation depth and select the appropriate types of prosthesis based on the patient's anatomy. The use of 3D modelling helps to optimise the placement of the prosthesis. Addressing anatomical features is key to reducing the risk of complications and improving the long-term results of arthroplasty

Keywords: arthroplasty; anatomical parameters; population ageing; quality of treatment; long-term results; optimisation of surgery; risk of complications

✦ INTRODUCTION

The issue of optimisation of preoperative planning for total hip arthroplasty (THA) has gained importance in modern orthopaedic surgery. Preoperative planning plays a critical role in determining the surgical strategy, choosing a prosthesis and establishing its optimal placement to achieve the best functional results and reduce the risk of postoperative complications. One of the key aspects that affect the success of THA is the accurate determination of the centre of rotation of the hip joint. The scientific community is increasingly recognising that the patient's anatomical parameters, in particular the pelvic angle, have a

significant impact on the determination of this centre of rotation, which in turn affects the overall surgical outcome.

A study by L. Yao *et al.* [1] determined that older patients who underwent hip or knee arthroplasty in the first six months after surgery reported functional limitations resulting from hip or knee-related symptoms. This study adds to the understanding of the factors that influence perceptions of participation among older patients undergoing hip or knee arthroplasty.

Similar clinical trials have been conducted in Ukraine, which may have an impact on the understanding of

Suggested Citation:

Zubkov O, Torchynskyi V. Effect of pelvic tilt on changing the centre of rotation of the hip joint in preoperative planning. Bull Med Biol Res. 2024;6(1):24–33. DOI: 10.61751/bmbr/1.2024.24

*Corresponding author



scientists about the importance of determining the pelvic angle before planning hip or knee prosthetics. The study by I. Zazirnyi [2] confirmed the safety and cost-effectiveness of THA, demonstrating significant progress in the development of less invasive surgical techniques, improvement of materials and technologies, which contributes to tissue preservation, implant durability, biocompatibility and ability to integrate with bone tissue. However, challenges such as the risk of infections and dislocations require additional research and improved clinical practices. The researcher draws attention to the importance of thoroughly testing innovations and monitoring their application, as well as the need to address biomechanical aspects, in particular the angle of the pelvis, to optimise the positioning of the prosthesis after THA. These findings may be related to pelvic tilt angle and hip prosthetics, as optimising posture and balance through rehabilitation can improve load distribution on the prosthetic joint, reducing the risk of complications and promoting better implant adaptation [3].

Additionally, studies have shown a close relationship between anatomical and biomechanical characteristics, such as pelvic tilt angle, and the occurrence of complications after arthroplasty. Optimisation of the positioning of the endoprosthesis, considering the individual characteristics of the patient, is critical to reducing the risk of instability, dislocation and other complications, ensuring the long-term functioning of the implant and improving the quality of life of patients [4, 5]. Thus, the integration of advanced surgical techniques, considering the anatomical features of each patient, is key to successful recovery and ensuring optimal long-term results of arthroplasty treatment [6].

Despite the existing results, there have not been enough studies conducted in this area. The main objective of the study was to prove that a change in the pelvic tilt angle affects the determination of the centre of rotation of the hip joint, which is critical in the preoperative planning of THA. This knowledge is necessary for accurate positioning of the prosthesis, minimising the risk of post-operative complications and ensuring better long-term treatment results.

✦ MATERIALS AND METHODS

The study was conducted at the Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine from January 2023 to January 2024. In this study, the main materials were dry pelvic and femoral bones, into which a 4 mm diameter steel ball was implanted in the femoral head to simulate a change in the centre of rotation. The bones had no pathologies or signs of chronic diseases that could affect the results of the study.

As for the balloon implantation technique, they were made of a special medical alloy that meets all quality standards and has a standard diameter of 4 mm. The balls were placed in the femoral head in a place that corresponds exactly to the area of the centre of rotation of the joint. This was done to accurately reproduce the physiological movement of the joint during the experiment. The ball was surgically fixed in the head of the femur. This process ensured that the ball was securely fixed in the correct position for the subsequent experiment. This method of ball implantation was used to accurately reproduce the conditions of joint movement and obtain reliable results of the study.

To obtain X-rays of the pelvis and femur with the implanted balloon, the patient bones were carefully positioned on the X-ray table in the desired position. The bones must be properly aligned to obtain high-quality images. The X-ray tube, which emits X-rays, was positioned according to the required geometry and angle to optimally visualise the pelvic and femoral bones. The obtained X-rays were processed using appropriate software to improve image quality and clarity. The images were analysed in detail to determine the exact centre of joint rotation. This measurement was carried out using specialised length and angle measurement software, which ensured high accuracy of the results. This innovative approach made it possible to visualise and measure the displacement of the centre of rotation with high accuracy using X-rays taken with the PLX 140 apparatus (USA). The device has a high X-ray power for high-quality images and the ability to adjust the position and orientation of the X-ray tube for precise positioning and obtaining the required images. The device can operate in a wide range of energies and frequencies, which allows it to be used for a variety of clinical applications. Built-in algorithms can be used to process the images captured, providing clear and detailed images. The technique was based on the implantation of a steel ball into the femoral head, which was performed to create a visual marker system for accurate tracking of the dynamics of the joint's centre of rotation during changes in the pelvic angle.

The PLX 140 X-ray machine played a critical role in the research study, as it was used to accurately determine the initial position of the centre of rotation of the hip joint and to document the changes caused by the modification of the pelvic angle. This stage of the study was particularly significant because it provided the ability to visualise and quantify the displacement of the centre of rotation resulting from changes in pelvic position. The use of an X-ray machine was used to obtain clear and detailed images, which are critical for accurate analysis of the biomechanical parameters of the hip joint. This approach not only improved the accuracy of the study but also opened new perspectives for understanding the relationship between the anatomical structure of the pelvis and the functional state of the hip joint, which is crucial for optimising preoperative planning and increasing the effectiveness of total hip replacement.

Modelling changes in the pelvic tilt angle was a key element of the study aimed at analysing the impact of pelvic anatomical variations on the position of the centre of rotation of the hip joint, which is crucial for the success of total joint replacement. As part of this experiment, a technique was used that allowed for precise and controlled changes in the angle of the pelvis from its natural position to angular deviations of 0, 10, 20, 30 and 40°. This systematic change in angles was implemented using specially designed setups and techniques that ensured high accuracy and reproducibility of the study conditions. To simulate changes in the angle of the pelvis, special devices were used to reproduce this change realistically. For fixing the bones, the machines were equipped with special fixators or holders that ensured stable fixation of the bones during the simulation. The components of the plants were made of strong and reliable materials such as plastic to ensure high stability and durability. The bones were fixed in a certain position employing fixators. By adjusting the angle of the pelvis with the help

of the devices, the change under study was reproduced. During the simulation, the position of the bones was measured and monitored to ensure that the change in pelvic angle was accurately reproduced.

In the context of the study, which revealed difficulties with hip prosthesis placement due to the high pelvic angle, the use of specially designed devices and techniques is key to optimising the arthroplasty procedure and minimising risks: 3D modelling and planning, navigation systems during operations using computer navigation or robotic systems. This detailed modelling allowed for an in-depth analysis of the biomechanical shifts in the position of the centre of rotation that occur as a result of changes in the pelvic angle. As part of the research, a comprehensive analysis was conducted of the impact of changes in the pelvic tilt angle on the position of the centre of rotation of the hip joint, which is essential for optimising preoperative planning for THA. For this purpose, specialised materials were prepared, including the collection of dry pelvic and femoral bones and the implantation of a steel ball into them. The method of modelling changes in the pelvic angle and recording the corresponding changes in the position of the centre of rotation on X-rays made it possible to conduct a detailed analysis of biomechanical changes in the hip joint. The application of this technique has opened the possibility of identifying critical angular deviations at which the displacement of the centre of rotation reaches such values that can significantly affect the mechanics of the hip joint and the efficiency of the endoprosthesis.

For the statistical analysis of the data in this study, specialised software was used to analyse medical images and measure the parameters of X-ray images. This software was able to accurately measure the displacements of the centre of rotation of the hip joint, which allowed for a highly accurate analysis of the effect of changes in the pelvic angle on the anatomical position and functionality of the hip joint. In addition, this software was used to identify subtle biomechanical changes associated with pelvic tilt modification and their potential impact on the choice of location and orientation of the hip replacement. Medical image processing software such as OsiriX (France) and ImageJ (USA) were used. These applications provide extensive capabilities for analysing and measuring X-ray image parameters, including a variety of statistical methods for processing the data.

All experimental procedures were carried out following the ethical principles established by the institution that conducted the study. Relevant ethical documents and standards that were addressed during the research include the Declaration of Helsinki [7], Belmont Report [8]. Additionally, the Guideline for Good Clinical Practice E6(R1) [9], Ethical Principles of Psychologists and Code of Conduct [10], and Data protection in the EU [11] were also considered.

RESULTS

The angle of the pelvis has a significant impact on the positioning of the hip prosthesis and its functionality after fitting. This is because the pelvic tilt angle determines the position of the acetabular component, which should be optimally oriented for normal hip biomechanics. Incorrect positioning of this component can lead to increased pressure on the prosthesis, which can cause wear, deformation

or even destruction. If the pelvic angle is too high or too low, this can lead to an incorrect distribution of the load on the hip joint, which in turn increases the risk of prosthesis dislocation, pain and limited mobility. It can also cause changes in the patient's gait and increase the risk of falls and injuries. Concerning the correlation between pelvic angle and the fitting process, the pelvic angle must be accurately considered when planning and fitting the acetabular component to achieve optimal prosthetic results. The angle of anteversion and lateral deviation should be carefully measured and considered to minimise the risk of the above complications. Modern technologies, such as computed tomography and computer modelling, allow surgeons to predict and plan interventions based on the individual characteristics of each patient. This approach optimised surgical outcomes and provided patients with a better quality of life after surgery.

In the context of this scientific experiment, an advanced technique was used to accurately and controllably modify the pelvic angle at intervals of 0, 10, 20, 30 and 40° from its baseline position. These angular changes were made using innovative devices and procedures designed to ensure precision and repeatability of the experimental conditions. This careful modelling approach allowed for a comprehensive analysis of the biomechanical displacements of the centre of rotation that occur in response to changes in pelvic angle. The use of this methodology was used to determine those critical angular parameters, upon reaching which the shift of the centre of rotation becomes so significant that it can affect the overall mechanics of the hip joint and the optimal functioning of the endoprosthesis. The image shows a pelvic model representing the natural position with a pelvic angle of 0° (Fig. 1). This is a standard starting position for modelling and determining the basic parameters of preoperative planning for hip arthroplasty.

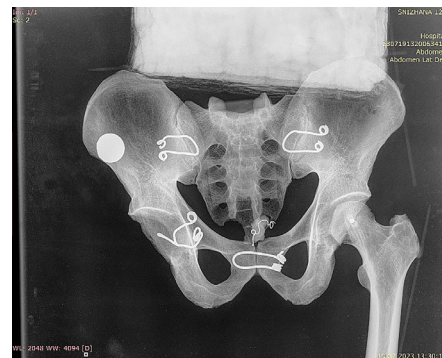


Figure 1. Simulate a 0° pelvic tilt angle
Source: compiled by the authors

X-ray markers visible on the femur are used to accurately assess the position of the centre of rotation. This image can be used to measure the pelvic tilt angle, which is important for analysing the potential impact of pelvic tilt on the long-term functionality and stability of the prosthesis. In this case, the zero pelvic tilt angle allows to definition of the “ideal” starting point from which additional measurements will be taken when the tilt is changed to higher angles, allowing for assessment changes in the position of the centre of rotation and deviation from the

optimal position of the prosthesis. The image has a clear view of the pelvis and femur, which can be used to identify anatomical features and potential areas for attention when planning prosthetics. Such a detailed analysis of bone structures in the context of preoperative planning is critical for successful hip arthroplasty.

Figure 2 shows an X-ray of an anatomical model of the pelvis simulating a horizontal orientation with a pelvic angle of 10° . This image serves as a starting point for the analysis of preoperative planning of hip arthroplasty and assessment of the basic parameters for the implantation of the prosthesis.

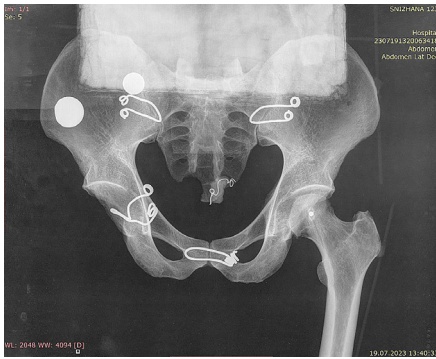


Figure 2. Simulate a 10° pelvic tilt angle

Source: compiled by the authors

The pelvic tilt angle of 10° creates the conditions for further measurements to assess the effect of different tilt angles on the centre of rotation of the joint and to identify abnormalities in the positioning of the endoprosthesis. The marked clarity of the visualisation of bone structures in the image allows you to examine the anatomical characteristics in detail and choose the optimal implantation strategy. Such a thorough analysis of the bone matrix plays a key role in preoperative planning, creating the basis for effective hip arthroplasty and ensuring the best clinical outcomes. In the X-ray, the pelvic angle was modified to 20° from the horizontal position, demonstrating the effect of the change in inclination on the positioning of the arthroplasty (Fig. 3).

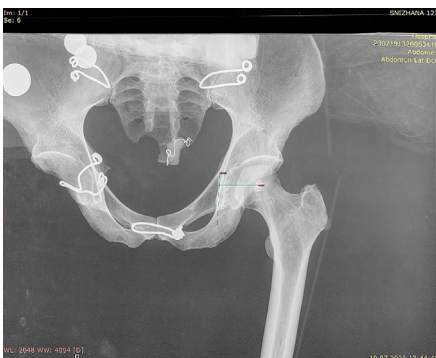


Figure 3. Simulate a 20° pelvic tilt angle

Source: compiled by the authors

This image has practical implications for preoperative planning, allowing orthopaedic surgeons to understand how changes in pelvic angle can affect optimal implant

placement (Fig. 3). The image shows that at an angle of inclination of 20° , changes occur that can potentially affect the biomechanics of the hip joint and determine the strategy for implant placement. The markers on the image can be used to measure the angular deviation and assess its impact on the position of the joint's centre of rotation. This data is critical for preventing complications such as implant wear or joint instability after surgery.

The X-ray image shows the pelvic skeleton with implanted metal structures with the pelvis tilted by 30° (Fig. 4). This deviation is performed to study biomechanical changes in the position of the implants and their orientation relative to the pelvic and femoral bones, which is important for preoperative planning.

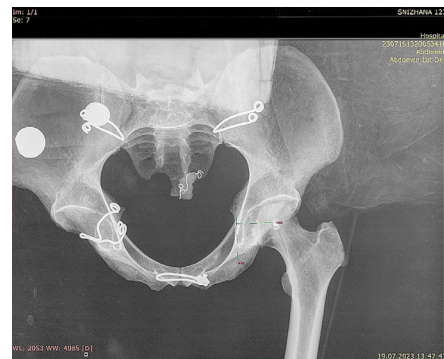


Figure 4. Simulate a 30° pelvic tilt angle

Source: compiled by the authors

A 30° shift in pelvic angle shows how a change in pelvic position can affect the angle of inclination, which then affects the functionality and service life of the prosthesis. This image provides valuable information for surgeons and engineers involved in biomechanics and implant design, allowing them to better understand the impact of anatomical deviations on optimal prosthetic positioning. The image can also be useful for developing personalised surgical plans, considering individual anatomical variations in patients.

The X-ray in Figure 5 shows a pelvic model used for scientific research with implanted markers that simulate a 40° change in pelvic angle. This image is intended to simulate physiological conditions to evaluate the effect of tilt angle on surgical planning for hip arthroplasty.

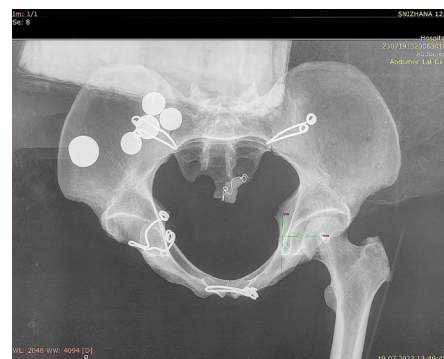


Figure 5. Simulate a 40° pelvic tilt angle

Source: compiled by the authors

Markers placed on the bone model are highlighted in bright white, indicating the use of a material with a high degree of radiopaque contrast. The image shows the anatomical structures of the pelvis and femur with metal markers on them. These markers accurately determine the position and orientation relative to the bones. The image illustrates a carefully planned placement of markers that can reproduce the corresponding angular changes in the position of the pelvic bones, which is important for preoperative modelling. It shows not only the bones themselves but also the spatial relationships between them, which is critical for planning the exact location of the endoprosthesis, its inclination and orientation, as well as for predicting changes in the load on the joint after surgery. This approach demonstrates the importance of advanced imaging techniques for optimising surgical strategy and may contribute to the development of more accurate algorithms for preoperative planning, risk reduction and improved patient care in orthopaedic surgery.

Based on the analysis of the data obtained, the study found that a change in the pelvic tilt angle significantly affects the location of the centre of rotation of the hip joint, which, in turn, has significant implications for the choice of optimal placement of the endoprosthesis and prevention of possible postoperative complications. The strategy for hip prosthetics at zero pelvic tilt and 40° tilt will be significantly different due to changes in anatomy and biomechanics that require a different approach to prosthesis planning and fitting. For example, at 0° of pelvic tilt, the prosthesis can be planned based on standard anatomy without the need for correction for significant anterior or posterior pelvic tilt. The angle of anteversion and inclusion of the acetabular component can be set closer to the “ideal” standard values, which are considered optimal for most patients. The general orientation of the implants concerning the bone structures is standard, which facilitates placement and ensures good functional results. At 40° of pelvic tilt, specialised planning is required to address the increased pelvic tilt, which can affect the positioning of the acetabular component and the need for correction to prevent excessive soft tissue tension or strain. It may be necessary to adjust the angle of implantation of the acetabular component to avoid improper loading of the prosthesis and reduce the risk of dislocation. Computer navigation and computer modelling become even more critical for the precise positioning of the implants concerning the abnormal pelvic position.

In general, the greater the pelvic angle, the more difficult it is to ensure the correct positioning of the acetabular component of the prosthesis and the greater the risks associated with improper load distribution, prosthesis wear and dislocations. This requires a more individualised approach to each patient and may require the use of non-standard implants or implantation techniques, as well as more thorough postoperative monitoring and rehabilitation. Fitting a hip prosthesis is a complex process that requires considering many individual anatomical features of the patient, including the angle of the pelvis. Depending on this angle, the prosthesis placement strategy may need to be adjusted. Assessment and correction of anteversion and inclusion of the denture cup should be performed. Anteversion is the angle at which the cup is placed in the acetabular bed. An

incorrect angle of anteversion can cause an increase or decrease in soft tissue tension around the prosthesis and affect the risk of dislocation. Furthermore, the depth of implantation of the acetabular component is adjusted and should consider changes in the anatomy that occur at different pelvic angles. This ensures that the load is evenly distributed over the prosthesis. Depending on the patient's anatomy and pelvic angle, it may be necessary to select specific types or models of prosthesis to optimise fit and functionality. With the help of 3D modelling and preoperative planning, it is possible to determine exactly how the pelvic angle will affect the position of the prosthesis and what adjustments need to be made for optimal positioning. Post-operative rehabilitation programmes should be adapted to the changes in biomechanics resulting from pelvic tilt to promote proper recovery and reduce the risk of complications. Taking these factors into account is important to ensure the long-term success of the prosthesis and reduce the risk of complications such as pain, limitation of movement, inappropriate loading and dislocation of the prosthesis.

The results of the study emphasise the importance of considering the individual anatomical features of the patient in the preoperative planning of THA. A detailed understanding of the relationship between the pelvic tilt angle and the position of the joint's centre of rotation allows for optimised surgical technique, maximised prosthesis functionality, and improved long-term treatment outcomes. Thus, the study makes an important contribution to the development of preoperative planning in orthopaedic surgery, providing a foundation for further scientific developments in this area.

★ DISCUSSION

The angle of the pelvis is a critical parameter that affects the biomechanics of the hip joint and its loading. Incorrect determination of this angle can lead to a shift in the centre of rotation of the joint, which in turn increases the risk of dislocation of the prosthesis, worsens functional outcomes, and may require revision surgery. The study used modern techniques, such as X-rays with modelling of the displacement of the centre of rotation, which allow for high accuracy in determining the angle of pelvic tilt and its impact on the position of the endoprosthesis.

The fact revealed in this study is that the pelvic tilt plays a significant role in the planning and fitting of hip arthroplasties, as it directly affects the functional anteversion and tilt of the acetabular component of the prosthesis. This understanding requires surgeons to take an individual approach to each case, based on a detailed analysis of the patient's anatomical features. These findings are echoed in the studies of such scholars as L. Yao *et al.* [1], J.D. Maratt *et al.* [12], Y. Kokubu *et al.* [13], who also studied the effect of pelvic tilt angle on the placement and functionality of hip arthroplasties. Their work emphasises the need to adapt the surgical strategy to this anatomical feature to improve the success of arthroplasty. The differences between studies are in the ways of assessing the effect of pelvic tilt and the methods of correcting the position of the acetabular component. While some researchers focus on the use of preoperative computed tomography or magnetic resonance imaging to determine the optimal position of the prosthesis, others suggest the use of an intraoperative

navigation system to achieve maximum accuracy in component placement. However, both lines of research emphasise the critical importance of preoperative planning and adaptation of surgical techniques to the individual anatomical characteristics of the patient. This encourages further scientific developments in the field of orthopaedic surgery to improve methods of assessment and planning of arthroplasty that consider the angle of inclination of the pelvis. The difference in approaches between the studies indicates the potential for future innovations in the field of orthopaedics, including the development of universal protocols for the assessment and planning of arthroplasty that would provide individualised and effective treatment of patients based on a comprehensive analysis of the anatomical and functional characteristics of the hip joint.

The fact that an individualised analysis of the hip joint anatomy, particularly the pelvic angle, is important is the starting point for a discussion with the study by H.H. Yun *et al.* [14]. Studies have highlighted the critical role of pelvic tilt angle in hip arthroplasty, emphasising its impact on prosthesis positioning and its potential to minimise the risks associated with prosthesis wear and dislocation. However, the study by the researchers addressed in detail the dynamics of pelvic tilt and rotation before and after surgery using advanced imaging techniques such as computed tomography and standing X-rays. This concludes that significant changes in pelvic tilt and rotation, which could affect the position of the prosthesis, usually do not occur [15, 16]. This study also highlights that pelvic tilt is crucial for an accurate assessment of the anteversion of the prosthesis cup, whereas pelvic rotation has less of an impact on this parameter. It coincides with those studies recognise the importance of anatomical planning and emphasise the need for individualised approaches to each patient to achieve optimal surgical outcomes. At the same time, the study by H.H. Yun *et al.* [14] adds a level of analysis, demonstrating that the stability of pelvic tilt and rotation after surgery is an indicator of successful prosthesis positioning, regardless of initial anatomical variations. The difference between these studies is in the methodology for assessing changes in the anatomical position of the pelvis and its impact on the orientation of the prosthesis. The researchers focus on specific metrics measured directly before and after surgery, which establishes a direct link between the stability of pelvic angular parameters and the success of arthroplasty. Thus, although the main conclusion about the importance of the pelvic angle in arthroplasty planning is the same, the study by the researchers provides a more in-depth analysis of the interaction between pelvic anatomical parameters and prosthesis positioning, using thorough imaging techniques.

The key discovery, which emphasises the importance of individualised analysis of the hip joint anatomy, especially the pelvic angle, before THA, has a deep resonance with the study conducted by T. Tateiwa *et al.* [17]. The research goes beyond traditional approaches to surgical planning, emphasising the need for a thorough understanding of the patient's anatomy to reduce the risk of complications and optimise treatment outcomes. The researchers focused on postoperative changes in global spinal sagittal alignment after hip arthroplasty, identifying the key role of accurate spinal positioning in preventing potential complications.

Similarly, the finding in this study highlights the importance of precise planning of the positioning of the hip prosthesis, considering the angle of the pelvis. In both cases, precision in planning surgical interventions is a key element in improving the effectiveness of treatment and minimising risks for patients. However, in contrast to the study by the researchers, which focuses on postoperative spinal alignment and its changes, this study focuses on the effect of pelvic angle on the planning and placement of hip prostheses. This difference in emphasis allows us to consider these studies as complementary, as they highlight different aspects of surgical planning and indicate the importance of a comprehensive approach to hip and spine surgery.

Both studies make a significant contribution to the development of preoperative planning in orthopaedic surgery, emphasising the need for an individualised approach based on a detailed analysis of each patient's anatomy. This reinforces the idea that the success of a surgical intervention depends on preliminary preparation and the ability to adapt surgical techniques to the patient's unique physiological characteristics. The authors' study, as well as that of other researchers [18-20], found that an increased pelvic tilt angle complicates the implantation of a hip prosthesis, increasing the risk of wear and dislocation, requiring an individual approach and postoperative care. The importance of assessing anatomical parameters such as anteversion and inclusion of the prosthesis is emphasised to optimise prosthesis positioning and reduce the risk of complications [21]. On the other hand, the study by T. Tateiwa *et al.* [17] focuses on the analysis of changes in global sagittal spinal alignment after THA, indicating the key role of accurate spinal positioning in preventing degenerative changes in the lumbar spine. It focuses on the impact of changes in pelvic and spinal position on long-term treatment outcomes, especially in cases with certain anatomical features. Both studies acknowledge the importance of individual anatomical characteristics in surgical planning and treatment strategy, emphasising the need for detailed preoperative analysis and planning. The main difference lies in the focus of the research. The first focuses on the implantation of a hip prosthesis and the associated risks due to the anatomy of the pelvis, while the second study looks at the impact of THA on the sagittal alignment of the spine, paying attention to long-term changes in the spinal column that can affect the patient's overall condition.

The key finding of the study is the critical role of individualised analysis of the hip joint anatomy, especially the pelvic angle, in preoperative planning for total hip replacement. This understanding allows surgeons to plan prosthesis placement more accurately, which helps to reduce the risk of complications, increase implant functionality and improve long-term patient outcomes. This research is leading to improvements in preoperative planning, including the use of advanced imaging techniques such as 3D modelling and the development of new surgical instruments and navigation systems to optimise prosthesis placement based on each patient's unique anatomy. This finding correlates with the study conducted by A. Eslam Pour *et al.* [22], A. Palit *et al.* [23], also focused on the study of changes in pelvic tilt and their impact on the functioning of hip prostheses. Their findings indicate that changes

in pelvic tilt, even by less than 10° , can cause significant problems, including the risk of prosthesis dislocation, depending on the patient's movements. Their findings highlight the importance of adapting prosthesis design, especially prosthesis head dimensions and stem angles, to minimise the risk of dislocation or impingement associated with changes in pelvic tilt. Studies demonstrate the importance of preoperative analysis and planning based on the patient's anatomy to optimise the results of THA. At the same time, this paper expands the understanding of this issue, emphasising the need to integrate advanced imaging techniques and develop the latest surgical tools to individualise surgical interventions. This, in turn, highlights the need for further research and technology development in this area to ensure the most effective and safe treatments for patients in need of arthroplasty.

The fact revealed in the study, which emphasises the critical importance of individualised analysis of the hip joint anatomy, especially the pelvic angle, before performing total hip arthroplasty, resonates with the work of such scientists as M. Okamoto *et al.* [24], C. Foissey *et al.* [5], also emphasise the importance of adequate monitoring and adjustment of the pelvic angle to ensure optimal placement of the endoprosthesis cup. Both studies emphasise that improper positioning of the prosthesis can lead to significant postoperative complications, including dislocation, increased wear of the prosthesis, and, as a result, reduced functionality and the need for repeated surgical interventions. The overlap between these studies lies in the recognition that accurate preoperative planning that addresses the individual anatomy of the patient is fundamental to achieving optimal surgical results. Thus, changing the angle of the pelvis requires not only accurate diagnosis before surgery but may also require the use of specialised surgical techniques and instruments to adapt to these unique features. Research also points to the potential benefits of using advanced technologies, such as 3D modelling and navigation systems, to improve the accuracy of endoprosthesis placement. However, the study by M. Okamoto *et al.* [24] has a specific focus on patients with low body mass index and a large range of internal rotation, which is important for identifying subgroups of patients at higher risk of pelvic tilt change. This emphasises the importance of not only universal approaches to planning and performing arthroplasty but also the need for a more detailed consideration of individual risk factors. Taking these addresses, it is possible to conclude that the integration of data from different studies contributes to the improvement of orthopaedic surgery practice, increasing the chances of successful intervention and minimising the risk of complications, which is an important contribution to the development of personalised medicine.

The fact that individualised analysis of the hip joint anatomy, particularly the pelvic angle, is important for planning THA is an important contribution to the practice of orthopaedic surgery. This insight allows surgeons to more accurately position the prosthesis, reducing the risk of complications, and improving implant functionality and overall patient outcomes. The development of preoperative planning methods, including the use of 3D modelling, creates prospects for further progress in orthopaedic

surgery and the development of personalised medicine. A study by H. Choe *et al.* [25], which indicates that repeated hip surgeries cause external rotation of the hip and increase the risk of collision and dislocation, especially in two-stage operations with muscle atrophy, demonstrates the importance of attention to anatomical details and potential changes after surgery. This study points to the difficulties that can arise due to anatomical changes after surgery and highlights the need to adapt surgical planning and postoperative care to minimise risks. Although studies have focused on anatomical features and their impact on surgical outcomes, the key discovery about the importance of pelvic tilt angle in planning for arthroplasty is complemented by the findings on the consequences of reoperation identified in the study by the researchers. Together, these studies highlight a comprehensive approach to hip surgery that requires a detailed understanding of the anatomy and potential joint changes to ensure the best possible treatment outcomes. The difference between the two is the emphasis on primary planning versus the complexities associated with re-operations, but they share a common commitment to minimising risks and improving patient outcomes by considering unique anatomical features.

Based on the studies presented, it is possible to conclude that pelvic tilt is a key parameter that has a significant impact on the success of total hip arthroplasty. Incorrect determination of this angle can lead to a shift in the centre of rotation of the joint, increasing the risk of dislocation of the prosthesis and the need for revision surgery. Modern imaging techniques, such as X-rays and computer modelling, allow for high accuracy in measuring the pelvic tilt and adapting the surgical approach to the individual anatomical features of the patient, which helps to optimise treatment outcomes and minimise the risk of complications. The interaction between the hip and the spine presents interesting challenges for the arthroplasty surgeon, requiring an in-depth assessment of both the coronal and sagittal planes during the planning of the operation. Understanding of this topic has improved significantly in recent years, but many questions remain. Well-designed prospective studies are needed to help identify and define how to integrate the sagittal plane into preoperative planning to determine optimal orientation to improve patient outcomes and load behaviour; only then can the benefits associated with the use of navigation/robotics reach their maximum potential, according to A. Premkumar *et al.* [26], G. Grammatopoulos *et al.* [27]. In comparison, the study by D. Kobayashi *et al.* [28] found an association between hip rotation and overall body alignment in patients undergoing THA. The authors emphasise the importance of considering hip rotation when planning and performing hip surgery to ensure optimal recovery. The study also noted that the interaction between the hip and spine poses a challenge to orthopaedic surgeons, requiring detailed planning of the operation, considering the coronal and sagittal planes. Despite significant progress in understanding this topic, there are still many unresolved issues that highlight the need for further research.

✦ CONCLUSIONS

When analysing the effect of changes in the pelvic tilt angle on the planning of hip arthroplasty, it should be

noted that this value is a key biomechanical parameter that affects the position and orientation of the acetabular component of the prosthesis.

As a result of the study using dry bone models with steel balls that simulate the centre of rotation of the femoral head, it became possible to measure and visualise the displacement of the centre of rotation with changes in the angle of inclination. During the experiment, using X-rays from the PLX 140, the displacement of the centre of rotation, which occurred when the pelvic angle was changed from 0 to 40°, was recorded. These studies have shown that with an increase in the pelvic tilt angle, there is a change in the position of the acetabular component of the prosthesis, which can lead to a change in the direction of loading on the prosthesis and the bone structures around it. This displacement can increase the risk of prosthesis dislocation, faster wear and other complications. Therefore, at 0° of pelvic tilt, preoperative planning can be based on standard anatomical landmarks and parameters, taking the typical position of the joint and prosthesis as a basis. However, with a significant pelvic tilt of 40°, it is neces-

sary to consider the changed geometry of the pelvic bones, which requires adjustment of implant angles and, possibly, the choice of specialised prosthesis types that would better adapt to the changed biomechanics. In addition, the preoperative planning must also be individually adapted to the increased tilt angle to ensure optimal recovery and reduce the risk of complications.

The study results highlight the importance of an individual approach to each arthroplasty case, where preoperative planning should be closely linked to the patient's precise anatomy and biomechanics. Therefore, it is possible to conclude that the range of pelvic tilt angles that should be considered when planning total arthroplasty should be expanded and the methods for determining these angles should be improved.

✦ ACKNOWLEDGEMENTS

None.

✦ CONFLICT OF INTEREST

The authors declare no conflict of interest.

✦ REFERENCES

- [1] Yao L, Jia Q, Wu J, Chai Y, Gao C, Wang Y, Li K, et al. Assessing perceived participation among older adults total hip arthroplasty and total knee arthroplasty patients six months post-surgery: A cross-sectional study. *Front Public Health*. 2023;11:1282461. DOI: [10.3389/fpubh.2023.1282461](https://doi.org/10.3389/fpubh.2023.1282461)
- [2] Zazirnyi I. Total hip arthroplasty during last 25 years. *Trauma*. 2020;21(5):32–41. DOI: [10.22141/1608-1706.5.21.2020.217088](https://doi.org/10.22141/1608-1706.5.21.2020.217088)
- [3] Mairesse S, Chazard E, Giraudet G, Cosson M, Bartolo S. Complications and reoperation after pelvic organ prolapse, impact of hysterectomy, surgical approach and surgeon experience. *Int Urogynecol J*. 2020;31:1755–61. DOI: [10.1007/s00192-019-04210-6](https://doi.org/10.1007/s00192-019-04210-6)
- [4] Okamoto M, Kawasaki M, Okura T, Ochiai S, Yokoi H. Comparison of accuracy of cup position using portable navigation versus alignment guide in total hip arthroplasty in supine position. *Hip Int*. 2021;31(4):492–99. DOI: [10.1177/1120700020908788](https://doi.org/10.1177/1120700020908788)
- [5] Foissey C, Batailler C, Fary C, Luceri F, Servien E, Lustig S. Transitioning the total hip arthroplasty technique from posterior approach in lateral position to direct anterior approach in supine position – Risk factors for acetabular malpositioning and the learning curve. *Int Orthop*. 2020;44:1669–76. DOI: [10.1007/s00264-020-04583-0](https://doi.org/10.1007/s00264-020-04583-0)
- [6] Vigdorichik JM, Sharma AK, Dennis DA, Walter LR, Pierrepont JW, Shimmin AJ. The majority of total hip arthroplasty patients with a stiff spine do not have an instrumented fusion. *J Arthroplasty*. 2020;35(6):252–54. DOI: [10.1016/j.arth.2020.01.031](https://doi.org/10.1016/j.arth.2020.01.031)
- [7] The World Medical Association. Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects [Internet]. [cited 2024 Jan 10]. Available from: <https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/>
- [8] Belmont Report: Ethical Principles and Guidelines for the Protection of Human Subjects of Research [Internet]. [cited 2024 Jan 10]. Available from: <https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/index.html>
- [9] European Medicines Agency. ICH Topic E 6 (R1) Guideline for Good Clinical Practice [standard online]. 2002 [cited 2024 Jan 10]. CPMP/ICH/135/95. Available from: https://www.ema.europa.eu/en/documents/scientific-guideline/ich-e6-r1-guideline-good-clinical-practice_en.pdf
- [10] Ethical Principles of Psychologists and Code of Conduct [Internet]. [cited 2024 Jan 10]. Available from: <https://www.apa.org/ethics/code>
- [11] Data protection in the EU [Internet]. [cited 2024 Jan 10]. Available from: https://commission.europa.eu/law/law-topic/data-protection/data-protection-eu_en
- [12] Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ. Pelvic tilt in patients undergoing total hip arthroplasty: When does it matter? *J Arthroplasty*. 2015;30(3):387–91. DOI: [10.1016/j.arth.2014.10.014](https://doi.org/10.1016/j.arth.2014.10.014)
- [13] Kokubu Y, Kawahara S, Kitamura K, Hamai S, Motomura G, Ikemura S, et al. Evaluation of the anterior acetabular coverage with a false profile radiograph considering appropriate range of positioning. *Sci Rep*. 2023;13:8288. DOI: [10.1038/s41598-023-35514-9](https://doi.org/10.1038/s41598-023-35514-9)
- [14] Yun HH, Murphy WS, Ward DM, Zheng G, Hayden B, Murphy SB. Effect of pelvic tilt and rotation on cup orientation in standing anteroposterior radiographs. *HIP Int*. 2020;30(1):48–55. DOI: [10.1177/1120700019831665](https://doi.org/10.1177/1120700019831665)
- [15] Szymański JK, Starzec-Proserpio M, Bartosińska-Raczkiewicz D, Krawczyk A, Kukulski P, Jakiel G. Impact of preoperative pelvic floor muscle function on the success of surgical treatment of pelvic organ prolapse. *Int Urogynecol J*. 2024;35(1):85–93. DOI: [10.1007/s00192-023-05653-8](https://doi.org/10.1007/s00192-023-05653-8)

- [16] Zhu H, Zhang D, Gao L, Liu H, Di Y, Xie B, et al. Effect of pelvic floor workout on pelvic floor muscle function recovery of postpartum women: Protocol for a randomized controlled trial. *Int J Environ Res Public Health*. 2022;19(17):11073. DOI: [10.3390/ijerph191711073](https://doi.org/10.3390/ijerph191711073)
- [17] Tateiwa T, Endo K, Matsuoka Y, Ishida T, Shishido T, Yamamoto K. Pelvic tilt after total hip arthroplasty in patients with osteoarthritis of the hip. *J Orthop Surg*. 2020;28(2):2309499020918317. DOI: [10.1177/2309499020918317](https://doi.org/10.1177/2309499020918317)
- [18] Fischer MCM, Tokunaga K, Okamoto M, Habor J, Radermacher K. Preoperative factors improving the prediction of the postoperative sagittal orientation of the pelvis in standing position after total hip arthroplasty. *Sci Rep*. 2020;10:15944. DOI: [10.1038/S41598-020-72782-1](https://doi.org/10.1038/S41598-020-72782-1)
- [19] Tezuka T, Heckmann ND, Bodner RJ, Dorr LD. Functional safe zone is superior to the Lewinnek safe zone for total hip arthroplasty: Why the Lewinnek safe zone is not always predictive of stability. *J Arthroplasty*. 2019;34(1):3–8. DOI: [10.1016/j.arth.2018.10.034](https://doi.org/10.1016/j.arth.2018.10.034)
- [20] Shimizu M., Kobayashi T, Chiba H, Jimbo S, Senoh I, Ito H. Adult spinal deformity and its relationship with hip range of motion: A cohort study of community-dwelling females. *Spine J*. 2019;19(7):1202–9. DOI: [10.1016/J.SPINEE.2019.02.006](https://doi.org/10.1016/J.SPINEE.2019.02.006)
- [21] Ohfuji S, Jingushi S, Kondo K, Takahashi S, Hirota Y. Epidemiology of hip osteoarthritis. *Rinsho Seikei Geka*. 2012;47(4):301–6. DOI: [10.11477/mf.1408102307](https://doi.org/10.11477/mf.1408102307)
- [22] Eslam Pour A, Schwarzkopf R, Patel KP, Anjaria MP, Lazennec JY, Dorr LD. How much change in pelvic sagittal tilt can result in hip dislocation due to prosthetic impingement? A computer simulation study. *J Orthop Res*. 2021;39(12):2604–14. DOI: [10.1002/jor.25022](https://doi.org/10.1002/jor.25022)
- [23] Palit A, King R, Hart Z, Gu Y, Pierrepont J, Elliott MT, Williams M.A. Bone-to-bone and implant-to-bone impingement: A novel graphical representation for hip replacement planning. *Ann Biomed Eng*. 2020;48(4):1354–67. DOI: [10.1007/S10439-020-02451-X](https://doi.org/10.1007/S10439-020-02451-X)
- [24] Okamoto M, Kawasaki M, Okura T, Seki T, Imagama S. Effects of body mass index and range of motion on intraoperative change in pelvic tilt during total hip arthroplasty using the direct anterior approach. *BMC Musculoskelet Disord*. 2021;22(1):240. DOI: [10.1186/s12891-021-04087-x](https://doi.org/10.1186/s12891-021-04087-x)
- [25] Choe H, Kobayashi N, Kobayashi D, Watanabe S, Abe K, Tezuka T, et al. Postoperative excessive external femoral rotation in revision total hip arthroplasty is associated with muscle weakness in iliopsoas and gluteus medius and risk for hip dislocation. *J Orthop Surg Res*. 2021;16:582. DOI: [10.1186/s13018-021-02744-4](https://doi.org/10.1186/s13018-021-02744-4)
- [26] Premkumar A, Almeida B, Ranawat CS, Jerabek SA, Esposito CI, Mayman DJ. Variability of pelvic axial rotation in patients undergoing total hip arthroplasty. *Hip Int*. 2021;31(2):215–22. DOI: [10.1177/1120700019889618](https://doi.org/10.1177/1120700019889618)
- [27] Grammatopoulos G, Innmann M, Phan P, Bodner R, Meermans G. Spinopelvic challenges in primary total hip arthroplasty. *EFORT Open Rev*. 2023;8(5):298–12. DOI: [10.1530/EOR-23-0049](https://doi.org/10.1530/EOR-23-0049)
- [28] Kobayashi N, Higashihira S, Kitayama H, Kamono E, Yukizawa Y, Oishi T, et al. Effect of decreasing the anterior pelvic tilt on range of motion in femoroacetabular impingement: A computer-simulation study. *Orthop J Sports Med*. 2021;9(4):2325967121999464. DOI: [10.1177/2325967121999464](https://doi.org/10.1177/2325967121999464)

Вплив нахилу таза на зміну центра ротації кульшового суглоба в передопераційному плануванні

Олександр Зубков

Аспірант

Інститут травматології та ортопедії Національної академії медичних наук України

01601, вул. Бульварно-Кудрявська, 27, м. Київ, Україна

<https://orcid.org/0009-0002-6763-5062>

Віктор Торчинський

Доктор медичних наук, старший науковий співробітник

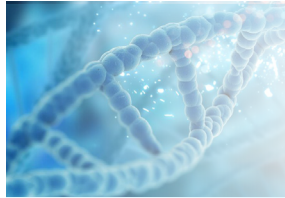
Інститут травматології та ортопедії Національної академії медичних наук України

01601, вул. Бульварно-Кудрявська, 27, м. Київ, Україна

<https://orcid.org/0000-0003-4818-9511>

Анотація. Зростаюча кількість ендопротезувань кульшового суглоба, пов'язана зі старінням населення, вимагає більш точних та ефективних методик планування операцій, щоб забезпечити успішність втручань і мінімізувати ризик ускладнень. Дослідження мало на меті показати, як зміна кута нахилу таза впливає на точне визначення центру ротації кульшового суглоба. У науковій роботі були використані сухі кістки таза та стегнової кістки з імплантованою сталевною кулькою діаметром 4 мм у голівці стегнової кістки для моделювання. Рентгенівські знімки виконувались за допомогою Рентген апарату PLX 140 для фіксації зміщення центру ротації. Дослідження підтвердило гіпотезу про те, що зміна кута нахилу таза призводить до зміщення центру ротації кульшового суглоба. Таке зміщення вимагає уваги при передопераційному плануванні, оскільки може вплинути на вибір та розміщення ендопротеза. Дослідження виявило, що великий кут нахилу таза ускладнює встановлення протеза кульшового суглоба, підвищуючи ризики зносу протеза та дислокацій. Це вимагає індивідуалізованого підходу до кожного пацієнта, використання спеціальних імплантатів та післяопераційного спостереження. Необхідно оцінювати антеверсію та інклінацію протеза, регулювати глибину імплантації та вибирати відповідні типи протезів, виходячи з анатомії пацієнта. Використання 3D-моделювання допомагає оптимізувати розміщення протеза. Врахування анатомічних особливостей є ключовим для зниження ризику ускладнень та покращення довгострокових результатів ендопротезування

Ключові слова: ендопротезування; анатомічні параметри; старіння населення; якість лікування; довгострокові результати; оптимізація хірургії; ризик ускладнень



Age-related changes in the cerebral hemispheres of male and female brains: A morphometric study using magnetic resonance imaging scans

Nataliia Maryenko*

PhD in Medical Sciences, Doctoral Student
Kharkiv National Medical University
61022, 4 Nauky Ave., Kharkiv, Ukraine
<https://orcid.org/0000-0002-7980-7039>

Abstract. Understanding the differences in brain ageing between males and females and the varying sensitivity of morphometric parameters to ageing are crucial for developing algorithms and protocols for objective and quantitative brain morphology evaluation in clinical practice. This study aimed to determine simple and applicable morphometric parameters for quantifying cerebral atrophic changes associated with ageing and to identify specific characteristics of these changes in ageing male and female brains. Two-dimensional magnetic resonance brain images from 100 participants without confirmed pathology of the nervous system, aged 18 to 86 years, were examined. The sample comprised 44 males and 56 females. Each participant underwent an assessment of five sections: four in the frontal plane (coronal sections) and one in the horizontal plane (axial section). The assessment involved the determination of perimeter and area values. Two measurement approaches were employed: one focusing solely on the visible surface of the cerebral hemispheres, and the other tracing the pial surface within the sulci. Derived indices, including perimeter-to-area ratios, shape factors, and ratios of perimeters and areas, were computed based on the acquired data. The study revealed more pronounced changes in absolute cross-sectional area values corresponding to overall brain tissue with ageing in males. However, no significant sex difference was observed in the age dynamics of relative values. The ratio of two cross-sectional brain areas, considering sulcal content and excluding it, has been identified as the most sensitive parameter to age-related changes in both male and female brains. This ratio could serve as an additional morphometric parameter for diagnostic purposes in examining cerebral structure

Keywords: ageing; morphometry; sex differences; tomography

✦ INTRODUCTION

The human brain undergoes an intricate and dynamic ageing process, characterised by morphological changes in various brain structures that can influence diverse functions of the nervous system. Currently, morphological alterations in the ageing brain can be evaluated non-invasively using diagnostic neuroimaging techniques, with magnetic resonance imaging (MRI) usually being the method of choice [1]. As highlighted by M.E. MacDonald *et al.* [1], MRI findings during healthy brain ageing encompass a wide range of structural and quantitative changes, with the most common including loss of brain volume and cortical thickness, which can be discerned through morphometry. The significance of studying age-related

changes is emphasised by the resemblance of normal ageing changes to those observed in pathological brain ageing, as evident in neurodegenerative diseases like Alzheimer's. The study by A. Chandra *et al.* [2] concludes that brain MRI serves as an informative biomarker for diagnosing Alzheimer's disease and mild cognitive impairment. However, the development of diagnostic criteria is still pending. The comprehensive review by D.B. Dubal [3] underscores the differing vulnerability of male and female brains to neurodegenerative changes. This is further supported by the conclusions drawn by T. Zalewska *et al.* [4], suggesting notable distinctions between male and female brains concerning neurodegenerative diseases and brain

Suggested Citation:

Maryenko N. Age-related changes in the cerebral hemispheres of male and female brains: A morphometric study using magnetic resonance imaging scans. *Bull Med Biol Res.* 2024;6(1):34–42 . DOI: 10.61751/bmbr/1.2024.34

*Corresponding author



ischaemia. Therefore, a crucial aspect of studying brain ageing, including Alzheimer's disease, is to ascertain the sex-specific characteristics of brain ageing in males and females, along with discerning changes in healthy ageing from those indicative of neurodegeneration.

Sexual dimorphism has been observed in various brain structures, as evidenced by morphometric studies utilizing diverse methodologies. For instance, a study by O. Boiagina & O. Vovk [5] utilizing MRI reported larger dimensions (circular area) of the corpus callosum in males compared to females. Similarly, research conducted by O. Slobodian *et al.* [6] on MRI brain scans revealed significant differences in the brain ventricular system between aged males and females with reported interhemispheric asymmetry in males.

Studies focusing on MRI-based morphometry of the overall cerebral hemispheres often employ either surface-based or volumetric morphometric approaches. For instance, D. Brennan *et al.* [7] utilised surface-based measurements of the cerebral cortex, including cortical thickness, cortical surface area, cortical volume, and sulcal depth, and developed a brain sex-predicting classifier based on these measurements.

P. Podgórski *et al.* [8] employed both volumetric and surface-based cortical measurements in their comprehensive morphometric investigation targeting brain ageing in males and females. Their study encompassed volumetric measurements of white matter, grey matter, and cerebrospinal fluid, along with the identification of surface-based parameters such as cortical thickness, sulcal depth, gyrification index, and fractal dimension.

Several studies have prioritised the volumetric approach when comparing age-related atrophic changes in male and female brains. For instance, in the study conducted by F. Sang *et al.* [9], a volumetric approach was chosen to measure total grey and white matter volumes in males and females. Similarly, A.M. Stickel *et al.* [10] utilised

volumetric measurements to assess global brain volume and grey matter volumes in specific brain regions such as the hippocampus, temporal, and occipital lobes. The study by Y. Wang *et al.* [11] employed volumetry to investigate subcortical volumes and their asymmetry in males and females during ageing. Additionally, N. Sambuco [12] applied a volumetric approach to assess the hippocampus and the amygdala in ageing male and female brains.

However, most of the surface-based and volumetric measurements require three-dimensional modelling, complicating the implementation of these metrics into clinical practice. Therefore, the simple morphometric approaches and algorithms adopted for two-dimensional MRI images commonly used in clinical practice deserve further exploration. This study aimed to identify straightforward and practical morphometric measures for assessing age-related cerebral atrophy and to delineate distinctive features of these alterations in the ageing brains of both men and women.

✦ MATERIALS AND METHODS

This work is a continuation of the previous study [13], where a comprehensive morphometric analysis was conducted using parameters derived from Euclidean ("classical") geometry. The current study expands on this by focusing on the sex differences in brain ageing. The morphometric analysis was carried out at the Histology, Cytology, and Embryology department of Kharkiv National Medical University (KNMU) during 2022 and 2023.

This research analysed MRI brain scans from a cohort comprising 100 individuals, consisting of 44 males and 56 females, aged between 18 and 86 years, with a mean age of 41.72 ± 1.58 years. The mean age for males was 41.43 ± 1.68 years, ranging from 18 to 86 years, and for females, it was 41.95 ± 1.51 years, ranging from 18 to 72 years. Table 1 shows the distribution of the study participants according to age and sex.

Table 1. The distribution of study participants according to age and sex

Age range, years	Males, N	Females, N	Total, N
18-30	14	17	31
31-45	14	15	29
46-60	8	16	24
61-86	8	8	16
Total	44	56	100

Source: compiled by the author

A 1.5 Tesla Siemens Magnetom Symphony magnetic resonance scanner (Siemens, Germany) was utilised for brain imaging. Two sequences were chosen for the study: T2 and fluid-attenuated inversion recovery (FLAIR). The MRI brain scans had the following specifications: a resolution of 72 dpi, with the absolute scale configured at 3 pixels = 1 mm. The distance between sections (slice thickness) was set at 5 mm.

For each participant, a series of tomographic sections (slices) from five distinct brain locations was selected. The frontal plane was utilised to acquire four coronal sections, designated as coronal 1 to 4, while the horizontal plane was

used to obtain one axial section (consequently, designated as axial). These specific sections were identified using precise anatomical landmarks: the first coronal section (coronal 1) corresponded to the level of the anterior poles of the temporal lobes, the second (coronal 2) to the level of the mammillary bodies, the third (coronal 3) to the level of the quadrigeminal plate, and the fourth (coronal 4) to the level of the splenium of the corpus callosum. The fifth, axial, section, was positioned at the level of the upper-middle portion of the thalamus. The chosen sections were selected based on their alignment with anatomical landmarks,

facilitating their easy identification and ensuring the representation of diverse regions within the cerebral hemispheres. Moreover, these sections are recognised for their association with common sites of pathological changes observed in neurodegenerative diseases [14].

The morphometric analysis relied on two fundamental parameters derived from Euclidean geometry: perimeter (P) and area (A). Both the perimeter and area were determined twice, in two stages (Fig. 1). The first stage involved measuring the perimeter and area, considering solely the superficially visible cerebral surface (Fig. 1A). The second stage involved measuring the perimeter and area encompassing the entire pial surface, including the surface

hidden in the sulci (Fig. 1B). Consequently, four primary parameters were obtained: perimeter P_A , representing the length of the visible cerebral surface contour; perimeter P_B , representing the length of the overall pial surface contour, encompassing sulci; area A_A , representing the cross-sectional overall brain area, including regions enclosed inside the sulci; and area A_B , representing the cross-sectional area of the overall brain tissue, excluding regions enclosed inside the sulci. Perimeter and area measurements were conducted using Adobe Photoshop CS5 Graphics Editor. Following scale fitting, the respective regions were outlined using the “select” tool, followed by measurement using the “analysis” tool.

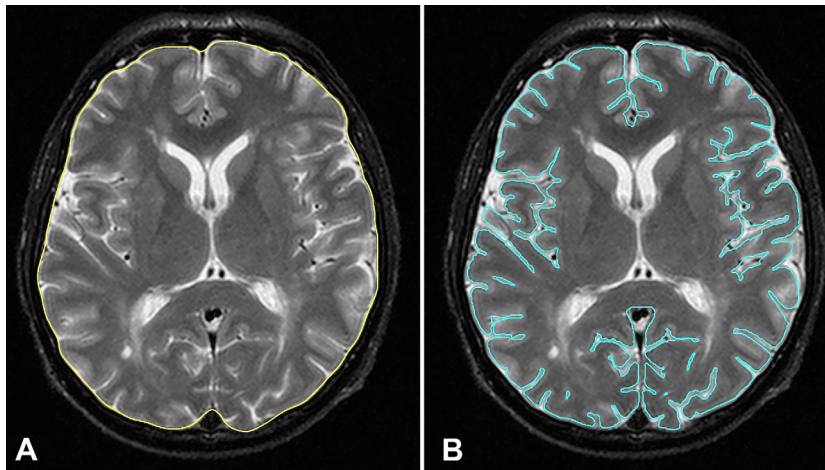


Figure 1. Two stages (A and B) for the morphometric analysis of MRI brain scans; axial section

Notes: A – measurement of perimeter P_A and area A_A along the superficially visible pial surface of the cerebral cortex; B – measurement of perimeter P_B and area A_B encompassing the entire pial surface of the cerebral cortex, with the pial surface hidden in the sulci

Source: the image is sourced from Kharkiv Radiologic Center; labelled by the author

Subsequently, several morphometric indices were computed from the acquired perimeter and area values. These included the following parameters: the perimeter-to-area ratios (P_A/A_A and P_B/A_B), the shape factors (circularity) (SF_A and SF_B), the ratio of two perimeters, or the gyrification index (P_B/P_A), and the ratio of two areas (A_B/A_A). The shape factors SF_A and SF_B (circularity) were calculated using the following formula:

$$SF = \frac{4\pi \times A}{P^2}, \quad (1)$$

where SF is the shape factor, A is the area, and P is the perimeter [15].

Statistical data processing involved Microsoft Excel 2016. The median values (percentile 50), interquartile ranges (Q1, or percentile 25, and Q3, or percentile 75), and minimum, and maximum values of the studied parameters were computed. The statistical significance of differences between morphometric parameters in males and females was evaluated using the Mann-Whitney U test. Spearman's rank correlation coefficient (r) was calculated to evaluate relationships between the studied morphometric parameters and age, with significance determined by the Student t -test. The F test was applied to compare linear regression equations characterizing the age dynamics of the studied

parameters in males and females (where age is an independent variable, and studied parameters are dependent variables). The significance level for all results was established at $\alpha=0.05$.

Brain scanning was conducted at the Kharkiv Radiologic Center for diagnostic purposes. The MRI brain scans were evaluated by radiology experts, and data from individuals without confirmed brain pathology on MRI were included in the study. These individuals were considered to have relatively normal brain anatomy. The study participants provided written informed consent. Anonymised MRI data were obtained under the requirements of the Kharkiv Radiologic Center. The study received approval from the Commission on Ethics and Bioethics of KNMU (Minutes of the Commission Meetings No. 10 dated November 7, 2018, and No. 5 dated February 1, 2023) for research involving human subjects. The study was conducted in compliance with the fundamental bioethical principles outlined in the Declaration of Helsinki [16].

★ RESULTS

Descriptive statistical data of morphometric parameter values are presented in Figure 2. This figure illustrates the comparison of median values for the studied parameters in males and females, along with the distribution of values.

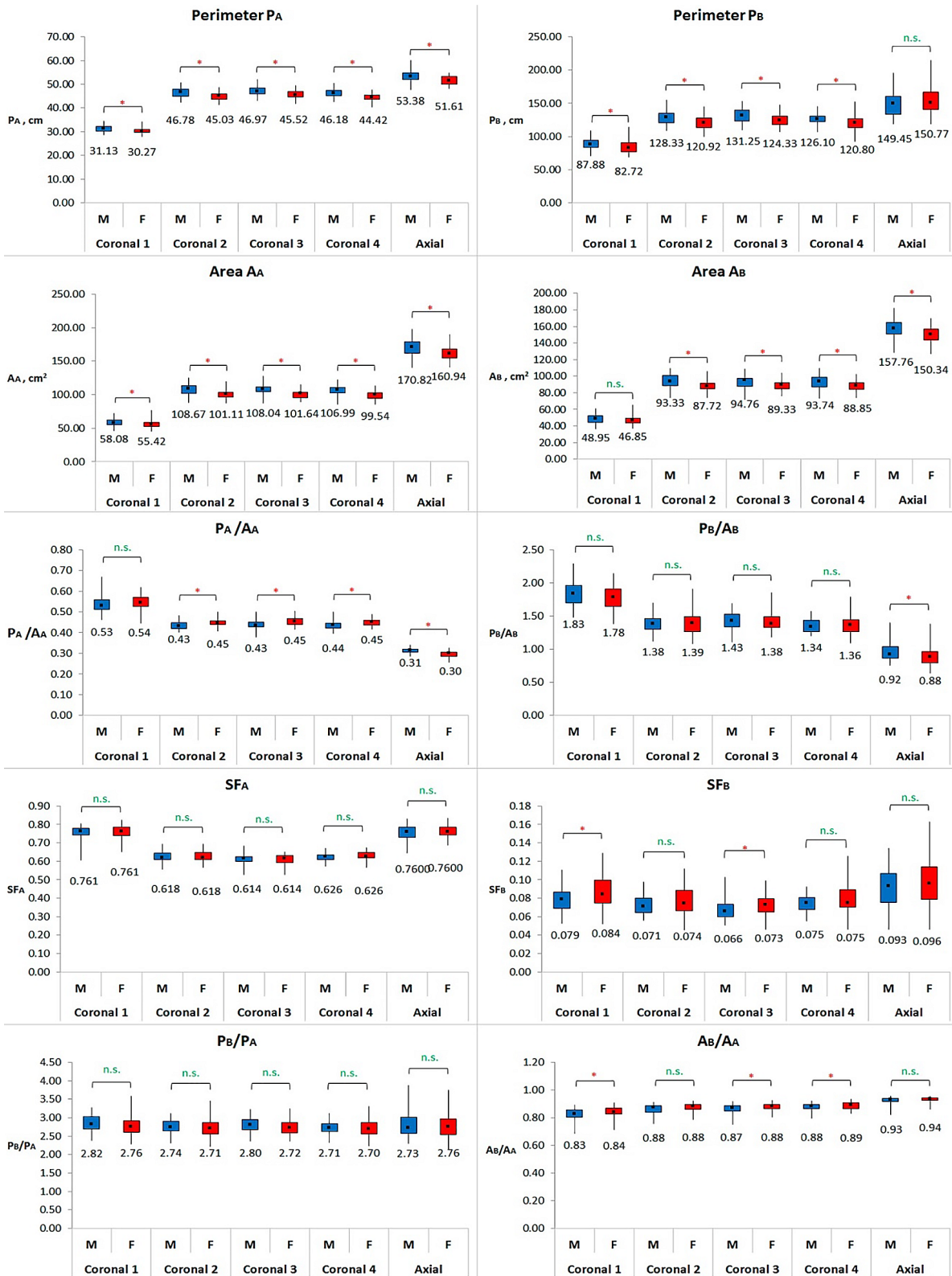


Figure 2. Descriptive statistics for morphometric parameters of cerebral hemispheres in males and females

Notes: M – males; F – females; P_A – perimeter measured along the visible cerebral surface only; P_B – perimeter measured along the entire cerebral pial surface; A_A – area measured along the visible cerebral surface only; A_B – area measured along the entire cerebral pial surface; SFA_A – shape factor (circularity) calculated from P_A and A_A values; SFA_B – shape factor (circularity) calculated from P_B and A_B values; the box plots depict the distribution of values, with median values provided below each box plot; * – $p < 0.05$ (significant sex difference); n.s. – $p > 0.05$ (non-significant sex difference)

Source: compiled by the author

As can be seen from Figure c2, the absolute values of both perimeter measures (P_A and P_B) were significantly larger in males in all examined brain sections, except for perimeter P_B in the axial section. Similarly, both area values (A_A and A_B) were significantly larger in males in all sections, except for area A_B in the first coronal section. This observation was expected and can be attributed to the sexual dimorphism in the absolute brain and head size between males and females.

When comparing derived indices in males and females, a diverse pattern was observed, depending on the section and parameter. The perimeter-to-area ratio P_A/A_A was statistically significantly different in all sections except the first coronal. However, the other perimeter-to-area ratio P_B/A_B did not statistically differ between males and females in all sections, except for the axial section.

Both shape factors did not differ between males and females in most sections (except for shape factor SF_B in

the first and third coronal sections). The gyrification index (the ratio of two perimeters, P_B/P_A) did not statistically differ between males and females in all sections. These findings suggest that there are no significant differences in the overall brain shape and gyrification degree between males and females, as assessed on the two-dimensional cross-sectional tomographic images.

The area ratio A_B/A_A was slightly higher in females in all investigated locations; however, a statistically significant difference was noted in the first, third, and fourth coronal sections.

Despite the presence of sexual dimorphism in brain structure and dimensions, it's important to note that some differences may arise from distinct patterns of brain ageing. To assess age-related changes, correlation analysis was conducted, as outlined in Table 2. The examined parameters demonstrated varying strength and direction of correlation relationships with age (Table 2).

Table 2. Correlation relationships between morphometric parameters of cerebral hemispheres and age in male and female brains

Parameter	Sex group	Brain section					
		Coronal 1	Coronal 2	Coronal 3	Coronal 4	Axial	All sections (average value)
P_A	Males	-0.212	-0.153	0.063	0.025	0.105	-0.019
	Females	-0.182	0.077	0.269	0.221	0.032	0.128
P_B	Males	-0.285	-0.083	0.133	-0.186	-0.008	-0.090
	Females	-0.209	-0.198	-0.033	-0.046	0.223	-0.045
A_A	Males	-0.194	-0.228	-0.166	-0.062	-0.027	-0.152
	Females	-0.222	-0.017	0.121	0.201	-0.017	0.037
A_B	Males	-0.442*	-0.374*	-0.428*	-0.191	-0.177	-0.384*
	Females	-0.392*	-0.268	-0.085	-0.041	-0.139	-0.189
P_A/A_A	Males	0.169	0.229	0.332*	0.141	0.220	0.232
	Females	0.212	0.087	0.080	-0.080	0.159	0.124
P_B/A_B	Males	0.245	0.400*	0.492*	0.055	0.145	0.379*
	Females	0.181	0.058	0.106	0.081	0.239	0.140
SF_A	Males	0.000	-0.082	-0.292	-0.189	-0.192	-0.370*
	Females	-0.108	-0.213	-0.283*	-0.166	-0.132	-0.324*
SF_B	Males	0.001	-0.178	-0.362*	0.080	-0.080	-0.170
	Females	-0.023	0.025	-0.076	-0.013	-0.240	-0.129
P_B/P_A	Males	-0.211	-0.031	0.098	-0.236	-0.008	-0.087
	Females	-0.167	-0.161	-0.177	-0.113	0.200	-0.110
A_B/A_A	Males	-0.429*	-0.561*	-0.568*	-0.388*	-0.445*	-0.549*
	Females	-0.521*	-0.503*	-0.545*	-0.514*	-0.379*	-0.579*

Notes: independent variable – age; P_A – perimeter measured along the visible cerebral surface only; P_B – perimeter measured along the entire cerebral pial surface; A_A – area measured along the visible cerebral surface only; A_B – area measured along the entire cerebral pial surface; SF_A – shape factor (circularity) calculated from P_A and A_A values; SF_B – shape factor (circularity) calculated from P_B and A_B values; * – $p < 0.05$

Source: compiled by the author

The values of both perimeters (P_A and P_B) did not show statistically significant correlations with age in both males and females. Similarly, statistically significant correlations between age and area A_A were not observed. However, area A_B showed a statistically significant decrease with age in males in the first, second, and third coronal sections, while

in females, a statistically significant decrease in this parameter was found only in the first coronal section. Therefore, this finding corresponds to a decrease in overall brain volume attributable to atrophic changes.

Both perimeter-to-area ratios did not show statistically significant correlations with age in most brain sections

in both males and females, except for P_A/A_A in the third coronal section and P_B/A_B in the second and third coronal sections in males. A similar pattern was found for both shape factor values: no significant changes in this parameter were observed with age in both males and females, except for shape factor SF_A in the third coronal section in females and shape factor SF_B in the third coronal section in males. Therefore, these findings suggest that there are no significant age-associated changes in the overall brain shape in both males and females.

The two-dimensional gyrification index P_B/P_A was not statistically significantly changed with age in both sex groups. The gyrification index allows for characterizing the convolutedness degree of the cerebral cortex surface – the more gyri the brain has on a particular tomographic section, the larger the area of the cortex surface hidden within the sulci, and the higher the ratio of perimeter P_B to perimeter P_A . It could be assumed that the gyrification index decreases with age, which may result from the smoothing of the surface of the cerebral cortex. However, concurrently with this, there is a deepening and widening of the sulci. Therefore, the relative portion of the perimeter corresponding to the cortical pial surface hidden within the sulci remains unchanged.

The area ratio A_B/A_A showed statistically significant negative correlations with age in both males and females in all examined brain sections. Compared to the related parameter, absolute area A_B , the ratio of the two areas showed higher correlations with age. The ratio of two areas can be considered a relative area value. The absolute area value can be influenced by variations in head and brain size, but the relative area offers advantages as it reduces the impact of absolute sizes and individual variability.

When comparing linear regression equations characterizing the age dynamics of the investigated parameters in two sex groups, most parameters were not significantly different in most sections. However, a statistically significant difference was observed between males and females in the linear regression equations characterizing the age dynamics of area A_B in the second and third coronal sections and the average area across all five sections ($p < 0.05$).

To summarise the findings, the investigated morphometric parameters can be classified into three distinct groups. The first group comprises primary perimeter and area values (P_A, P_B, A_A, A_B) that characterise the absolute dimensions of the brain. It is noteworthy that these parameters exhibited higher values in males, and more pronounced age-related changes in absolute area A_B were observed in males.

The second group of parameters consisted of calculated relative indices (perimeter-to-area ratios P_A/A_A and P_B/A_B , shape factors SF_A and SF_B , and gyrification index P_B/P_A) characterizing the features of brain shape. These parameters showed nearly identical or closely matched values in both males and females across most tomographic sections. Additionally, this group of parameters did not demonstrate age-related changes in either sex group.

The third group comprises only one parameter – the ratio of areas A_B/A_A . This parameter exhibited significant correlation relationships with age, which were the strongest among all studied parameters. This parameter exhibited a similar association with age in both males and females, making it the most sensitive and informative measure when characterizing age-related changes in the brains of both sex groups.

DISCUSSION

This study focused on determining simple and applicable morphometric parameters for cerebral hemispheres, easily measurable through conventional two-dimensional MRI brain scans. Specifically, parameters such as perimeter and area, derived from Euclidean geometry, were determined. Additionally, the study calculated additional morphometric indices and assessed their changes in age.

When comparing the age-related dynamics of various parameters, the calculated index A_B/A_A emerged as the most responsive to age-related changes. This index signifies the ratio of area A_B , corresponding to brain tissue excluding sulci, to area A_A , encompassing sulcal content. In contrast to absolute morphometric parameter values, this index demonstrated similar sensitivity to age-associated changes in both genders. The widening of sulci with age, attributed to brain tissue atrophy, leads to an increase in the volume corresponding to sulcal content, resulting in a reduction in the ratio A_B/A_A . The widening of sulci has been linked to the documented increase in cerebrospinal fluid volume as described by P. Podgórski *et al.* [8]. This finding further aligns with the MRI findings reported by O. Slobodian *et al.* [6] regarding age-related changes in the brain's ventricular system. Although those authors reported sex differences in brain ventricles in aged persons, the present study did not find sex differences in the age-associated increase of cerebrospinal fluid occupying the cerebral sulci.

The parameter most closely resembling the areas' ratio A_B/A_A , or relative brain area, is intracranial volume [17, 18], which serves as a three-dimensional counterpart to the studied parameter and intracranial area. The study by S. Yamada *et al.* [17] affirmed the reliability of estimating cerebrospinal fluid volume alongside intracranial volume measurement for characterizing ageing changes. However, S. Nerland *et al.* [18] reported that the methods for intracranial volume estimation significantly influence the reliability and informativeness of the obtained data. The main difference between approaches used in the present and previous studies, aside from dimensionality, lies in the method of measurement. The current approach involves measuring area A_A along the external visible surface of the hemispheres, whereas intracranial volume is defined by the inner surface of the skull bones. The current approach offers advantages by specifically characterizing sulcal widening without considering the influence of the space between the skull and brain, including the subarachnoid space, the volume of which can vary and impact the accuracy of age-related change determinations.

The observed differences in brain ageing between males and females can be elucidated by several factors. A notable finding is the more pronounced age-related decline in the absolute cross-sectional area A_B in males. This discrepancy suggests a greater volume loss in the male brain over time. Given that males typically possess larger absolute brain dimensions, they may exhibit a more substantial reduction in absolute size with ageing. However, it is noteworthy that the age dynamics of the relative area, indicated by the ratio of the two areas, did not exhibit significant differences between males and females. This implies that, when considering relative area values, which account for variations in head and brain size, the age-related changes are comparable between the sexes. Furthermore, other derived

parameters characterizing brain shape, including shape factor, perimeter-to-area ratio, and gyrification index, did not demonstrate significant age-related changes and did not show significant differences in terms of sex. These findings suggest that while there may be differences in absolute brain volume changes with age between males and females, overall brain shape and structural complexity remain relatively stable across genders throughout the ageing process.

A prior investigation, conducted on the identical sample as the current study, employed fractal analysis to assess cerebral atrophy in terms of ageing [19]. The fractal dimension of the cerebral hemispheres' pial surface was identified as a sensitive indicator of age-related changes. However, this parameter did not show differences in cerebral hemispheres' complexity and ageing dynamics between males and females. Several prior studies have reported more noticeable age-associated alterations in males compared to females, while others demonstrated no age-gender interactions, or earlier and stronger declines in cortical parameters in females. Thus, the study by O. Podgórski *et al.* [8] reported that while both male and female brains exhibited signs of ageing starting at approximately 45 years old, females exhibited more pronounced age-related changes in morphometric parameters of the cerebral cortex: the thickness of the cerebral cortex, depth of sulci, gyrification index, and fractal dimension). This conclusion is bolstered by the findings of the study conducted by F. Sang *et al.* [9], which described the more pronounced age-associated decline in brain grey matter volumes in females. Simultaneously, the authors have reported no sex-related differences in white matter ageing.

Conversely, A.M. Stickel *et al.* [10] reported contrasting results, concluding that global brain volumes, as well as the volume of grey matter in several brain regions, exhibited less decline with age in males compared to females. Additionally, the study by Y. Wang *et al.* [11] corroborates these findings, reporting a faster decline in the volumes of subcortical structures in males. The volumetric study by N. Sambuco [12] reported a larger amygdala in males, but after the volume normalization, no sex differences were evident in the ageing patterns of the hippocampus and the amygdala.

The diverse array of results in this study and previous research by other authors may be linked to the specific morphometric parameters chosen, with varying sensitivity to age-related changes and heterogeneity in the samples. The studies of L.M. Wierenga *et al.* [20] and N.J. Forde *et al.* [21] have described greater variability in morphometric parameters in males, consistent with the somewhat larger interquartile range of area A_b in males observed in the present study. The substantial variability of morphometric parameters in the male brain may influence results in sample formation and account for differing degrees of age-related changes. Given the variability in absolute values, using relative calculated indices, such as the A_b/A_A ratio or intracranial volume, is more appropriate and informative.

The gender and sex-related differences in morphological changes in the ageing brain, as assessed by morphometric studies, may influence the functional state of the brain. Thus, F. Cieri *et al.* [22] and Z. Yang *et al.* [23] in their studies have shown the impact of sex on brain functional topology and connectivity during normal ageing, mild cognitive impairment, and Alzheimer's disease.

Consequently, morphological and functional changes may contribute to sex differences in cognitive decline during ageing. It has been reported by B.H. Lee *et al.* [24] and K. Wolfova *et al.* [25] that behavioural symptoms may vary between males and females in normal ageing, as well as in cognitive and behavioural impairment. Among the potential factors influencing the diverse patterns of brain ageing in males and females are the effects of sex hormones, as reported by C. Gurvich *et al.* [26], variations in blood plasma lipid profiles, as concluded by Q. Tian *et al.* [27], and congenital features of brain microstructure, as considered by E.T. Reas *et al.* [28]. However, the exact nature of these sex differences is still under investigation. Understanding these differences is essential for developing diagnostic protocols and targeted interventions for age-related cognitive impairments.

✦ CONCLUSIONS

Firstly, this study sought to identify simple and applicable morphometric parameters to measure cerebral atrophy changes linked with ageing. Among the studied Euclidean geometry-derived parameters, the most sensitive parameter to age-related changes, identified across both genders, was the ratio of two cross-sectional brain areas, considering sulcal content and excluding it. It has shown significant negative correlation relationships with age: $r = -0.549$ in males, and $r = -0.579$ in females for the average value of all brain sections. This finding suggests its potential utility as an additional morphometric parameter for quantitatively assessing age-related atrophic brain changes within clinical practice. The morphometric approach used in the present study offers advantages such as simplicity, applicability, and compatibility with a wide range of software. This metric approach can serve as a standalone morphometric method as well as a supportive preliminary measurement to assess the necessity of more complicated morphometric studies.

Secondly, the study aimed to identify the specific characteristics of changes in the studied parameters in the ageing male and female brains. The present study revealed that as individuals age, males exhibit more pronounced alterations in the absolute size of the cross-sectional area corresponding to overall brain tissue compared to females. In contrast, the age-related trends of relative values showed no notable differences between male and female brains. The derivative indices characterizing brain shape did not show significant sex differences, nor did they show age-related changes. Since the values of several assessed parameters differed in males and females, it is highly advisable to take into account the values calculated for both genders. Further research in this area requires an assessment of the sensitivity and informativeness of morphometric parameters in diagnosing neurodegenerative diseases and distinguishing between normal brain ageing and neurodegenerative diseases.

✦ ACKNOWLEDGEMENTS

The author wishes to extend heartfelt thanks to the participants of this study, whose invaluable contribution made this research endeavour achievable.

✦ CONFLICT OF INTEREST

The author declares no conflict of interest.

◆ REFERENCES

- [1] MacDonald ME, Pike GB. MRI of healthy brain ageing: A review. *NMR Biomed.* 2021;34(9):e4564. DOI: [10.1002/nbm.4564](https://doi.org/10.1002/nbm.4564)
- [2] Chandra A, Dervenoulas G, Politis M, Alzheimer's Disease Neuroimaging Initiative. Magnetic resonance imaging in Alzheimer's disease and mild cognitive impairment. *J Neurol.* 2019;266(6):1293–2. DOI: [10.1007/s00415-018-9016-3](https://doi.org/10.1007/s00415-018-9016-3)
- [3] Dubal DB. Sex difference in Alzheimer's disease: An updated, balanced and emerging perspective on differing vulnerabilities. *Handbook of Clin Neurol.* 2020;175:261–73. DOI: [10.1016/B978-0-444-64123-6.00018-7](https://doi.org/10.1016/B978-0-444-64123-6.00018-7)
- [4] Zalewska T, Pawelec P, Ziabska K, Ziemka-Nalecz M. Sexual dimorphism in neurodegenerative diseases and in brain ischemia. *Biomolecules.* 2023; 13(1):26. DOI: [10.3390/biom13010026](https://doi.org/10.3390/biom13010026)
- [5] Boiagina O, Vovk O. Method of the morphometric analysis of the corpus callosum form on the basis of MR-images and applicable to its natural preparations. *Inter Collegas.* 2019;6(3):150–54. DOI: [10.35339/ic.6.3.150-154](https://doi.org/10.35339/ic.6.3.150-154)
- [6] Slobodian O, Kryvetskiy V, Khmara T. Morphometric characteristics of the ventricular brain systems in the elderly age. *Clin Anat Oper Surg.* 2020;19(4):15–19. DOI: [10.24061/1727-0847.19.4.2020.45](https://doi.org/10.24061/1727-0847.19.4.2020.45)
- [7] Brennan D, Wu T, Fan J. Morphometrical brain markers of sex difference. *Cereb Cortex.* 2021;31(8):3641–49. DOI: [10.1093/cercor/bhab037](https://doi.org/10.1093/cercor/bhab037)
- [8] Podgórski P, Bładowska J, Sasiadek M, Zimny A. Novel volumetric and surface-based magnetic resonance indices of the aging brain – does male and female brain age in the same way? *Front Neurol.* 2021;12:645729. DOI: [10.3389/fneur.2021.645729](https://doi.org/10.3389/fneur.2021.645729)
- [9] Sang F, Chen Y, Chen K, Dang M, Gao S, Zhang Z. Sex differences in cortical morphometry and white matter microstructure during brain aging and their relationships to cognition. *Cereb Cortex.* 2021;31(11):5253–62. DOI: [10.1093/cercor/bhab155](https://doi.org/10.1093/cercor/bhab155)
- [10] Stickel AM, Tarraf W, González KA, Ivanovic V, Morlett Paredes A, Zeng D, et al. Characterizing age- and sex-related differences in brain structure among middle-aged and older Hispanic/Latino adults in the study of Latinos-investigation of neurocognitive aging magnetic resonance imaging (SOL-INCA MRI). *Neurobiol Aging.* 2023;126:58–66. DOI: [10.1016/j.neurobiolaging.2023.02.007](https://doi.org/10.1016/j.neurobiolaging.2023.02.007)
- [11] Wang Y, Xu Q, Luo J, Hu M, Zuo C. Effects of age and sex on subcortical volumes. *Front Aging Neurosci.* 2019;11:259. DOI: [10.3389/fnagi.2019.00259](https://doi.org/10.3389/fnagi.2019.00259)
- [12] Sambuco N. Sex differences in the aging brain? A voxel-based morphometry analysis of the hippocampus and the amygdala. *Neuroreport.* 2021;32(16):1320–24. DOI: [10.1097/WNR.0000000000001728](https://doi.org/10.1097/WNR.0000000000001728)
- [13] Maryenko N, Stepanenko O. Atrophic age-related changes in cerebral hemispheres: Euclidean geometry based morphometry of MRI brain scans. *Acta Morphol Anthropol.* 2023;30(3-4):40–52. DOI: [10.7546/AMA.30.3-4.2023.06](https://doi.org/10.7546/AMA.30.3-4.2023.06)
- [14] King RD, George AT, Jeon T, Hynan LS, Youn TS, Kennedy DN, et al. Characterization of atrophic changes in the cerebral cortex using fractal dimensional analysis. *Brain Imaging Behav.* 2009;3:154–66. DOI: [10.1007/s11682-008-9057-9](https://doi.org/10.1007/s11682-008-9057-9)
- [15] Underwood EE. *Quantitative stereology.* 2nd ed. Reading: Addison-Wesley Publishing Company; 1970. 274 p.
- [16] The World Medical Association. Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects [Internet]. [cited 2023 Dec 21]. Available from: <https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/>
- [17] Yamada S, Otani T, Ii S, Kawano H, Nozaki K, Wada S, et al. Aging-related volume changes in the brain and cerebrospinal fluid using artificial intelligence-automated segmentation. *Eur Radiol.* 2023;33:7099–12. DOI: [10.1007/s00330-023-09632-x](https://doi.org/10.1007/s00330-023-09632-x)
- [18] Nerland S, Stokkan TS, Jørgensen KN, Wortinger LA, Richard G, Beck D, et al. A comparison of intracranial volume estimation methods and their cross-sectional and longitudinal associations with age. *Hum Brain Mapp.* 2022;43(15):4620–39. DOI: [10.1002/hbm.25978](https://doi.org/10.1002/hbm.25978)
- [19] Maryenko N, Stepanenko O. Quantitative characterization of age-related atrophic changes in cerebral hemispheres: A novel “contour smoothing” fractal analysis method. *Transl Res Anat.* 2023;33(8):100263. DOI: [10.1016/j.tria.2023.100263](https://doi.org/10.1016/j.tria.2023.100263)
- [20] Wierenga LM, Doucet GE, Dima D, Agartz I, Aghajani M, Akudjedu TN, et al. Greater male than female variability in regional brain structure across the lifespan. *Hum Brain Mapp.* 2022;43(1):470–99. DOI: [10.1002/hbm.25204](https://doi.org/10.1002/hbm.25204)
- [21] Forde NJ, Jeyachandra J, Joseph M, Jacobs GR, Dickie E, Satterthwaite TD, et al. Sex differences in variability of brain structure across the lifespan. *Cereb Cortex.* 2020;30(10):5420–30. DOI: [10.1093/cercor/bhaa123](https://doi.org/10.1093/cercor/bhaa123)
- [22] Cieri F, Yang Z, Cordes D, Caldwell JZK, Alzheimer's Disease Neuroimaging Initiative. Sex differences of brain functional topography revealed in normal aging and Alzheimer's disease cohort. *J Alzheimers Dis.* 2021;80(3):979–84. DOI: [10.3233/JAD-201596](https://doi.org/10.3233/JAD-201596)
- [23] Yang Z, Cieri F, Kinney JW, Cummings JL, Cordes D, Caldwell JZK, Alzheimer's Disease Neuroimaging Initiative. Brain functional topology differs by sex in cognitively normal older adults. *Cereb Cortex Commun.* 2022;3(3):tgac023. DOI: [10.1093/texcom/tgac023](https://doi.org/10.1093/texcom/tgac023)
- [24] Lee BH, Richard JE, de Leon RG, Yagi S, Galea LAM. Sex differences in cognition across aging. *Curr Top Behav Neurosci.* 2023;62:235–84. DOI: [10.1007/7854_2022_309](https://doi.org/10.1007/7854_2022_309)
- [25] Wolfova K, Creese B, Aarsland D, Ismail Z, Corbett A, Ballard C, et al. Gender/sex differences in the association of mild behavioral impairment with cognitive aging. *J Alzheimers Dis.* 2022;88(1):345–55. DOI: [10.3233/JAD-220040](https://doi.org/10.3233/JAD-220040)
- [26] Gurvich C, Thomas N, Kulkarni J. Sex differences in cognition and aging and the influence of sex hormones. *Handbook of Clin Neurol.* 2020;175:103–15. DOI: [10.1016/B978-0-444-64123-6.00008-4](https://doi.org/10.1016/B978-0-444-64123-6.00008-4)

- [27] Tian Q, Mitchell BA, Erus G, Davatzikos C, Moaddel R, Resnick SM, Ferrucci L. Sex differences in plasma lipid profiles of accelerated brain aging. *Neurobiol Aging*. 2023;129:178–84. DOI: [10.1016/j.neurobiolaging.2023.05.013](https://doi.org/10.1016/j.neurobiolaging.2023.05.013)
- [28] Reas ET, Hagler DJ, Zhong AJ, Lee RR, Dale AM, McEvoy LK. Brain microstructure mediates sex-specific patterns of cognitive aging. *Aging*. 2021;13(3):3218–38. DOI: [10.18632/aging.202561](https://doi.org/10.18632/aging.202561)

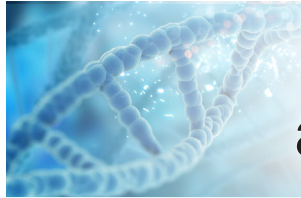
Вікові зміни великих півкуль головного мозку чоловіків та жінок: морфометричне дослідження магнітно-резонансних томограм

Наталія Мар'єнко

Кандидат медичних наук, докторант
Харківський національний медичний університет
61022, просп. Науки 4, м. Харків, Україна
<https://orcid.org/0000-0002-7980-7039>

Анотація. Розуміння відмінностей у старінні головного мозку чоловіків та жінок і різної чутливості морфометричних параметрів до вікових змін має важливе значення для розробки алгоритмів і протоколів для об'єктивної та кількісної оцінки будови головного мозку в клінічній практиці. Метою цього дослідження було визначити прості і застосовні морфометричні параметри для кількісної оцінки вікових змін у великих півкулях головного мозку та виявити специфічні особливості цих змін при старінні головного мозку у чоловіків і жінок. Були досліджені двовимірні магнітно-резонансні томограми головного мозку 100 осіб у віці від 18 до 86 років без підтвердженої патології нервової системи. До вибірки увійшли 44 чоловіка та 56 жінок. Дослідження головного мозку кожного учасника включало аналіз п'яти томографічних зрізів, у тому числі чотирьох у фронтальній площині (корональні зрізи) і одного у горизонтальній площині (аксіальний зріз). Морфометрія включала визначення значень периметра та площі. Було використано два підходи до вимірювання: один включав визначення периметра та площі відповідно до видимої поверхні півкуль головного мозку, а інший включав вимірювання цих показників відповідно до усієї поверхні півкуль, включно із поверхнею, прихованою в борознах. На основі отриманих значень периметра та площі були розраховані похідні індекси, у тому числі відношення периметра до площі, фактори форми та співвідношення периметрів і площ. Дослідження показало, що з віком у чоловіків спостерігаються більш виражені зміни абсолютних значень площі перерізу, що відповідає тканині мозку в цілому. Проте вікова динаміка відносних величин у чоловіків і жінок достовірно не відрізнялася. Виявлено, що співвідношення двох площ перерізу мозку, з урахуванням вмісту борозн та без нього, виявилось параметром, найчутливішим до вікових змін як у чоловіків, так і у жінок. Це співвідношення може слугувати додатковим морфометричним параметром для дослідження структури головного мозку з діагностичною метою

Ключові слова: старіння; морфометрія; статеві відмінності; томографія



Exploring water disinfection through electrolytic ozonation for application in wartime conditions

Taras Pyatkovskyy*

PhD in Medical Sciences, Associate Professor
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0003-1240-1680>

Olena Pokryshko

PhD in Medical Sciences, Associate Professor
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0001-9640-0786>

Serhii Danylkov

PhD in Medical Sciences, Assistant Professor
Bogomolets National Medical University
01601, 13 Taras Shevchenko Blvd, Kyiv, Ukraine
<https://orcid.org/0009-0008-7273-4296>

Abstract. Clean and safe water is a fundamental requirement for human survival and well-being. The destruction of civilian infrastructure during wars or natural disasters can severely limit access to clean water for the local population, military, rescue workers and volunteers. The objective of the study was the evaluation of the efficiency of fresh water disinfection by electrolytic ozonation. The ozone concentration was measured photometrically by the intensity of the colour change in the reaction with N, N-diethyl-p-phenylenediamine sulfate. The water quality was assessed microbiologically by determining the total microbial count of the samples and by analysing the colour of the bottom of the flasks in which the water samples were stored. The efficiency of ozonation of artesian water in the field was evaluated. Electrolytic ozonation of 500 mL of spring water for two and five minutes produced an aqueous ozone solution with a concentration of 0.74 and 1.72 mg/L, respectively. Electrolytic ozone decomposed slowly and was detected in the samples three days after the water treatment. Ozonation of spring water for 5 and 10 minutes effectively inactivated all natural microorganisms (2.11 log CFU/mL), the water remained sterile and without any colour changes for a month. Water samples ozonated for 2 minutes did not demonstrate any visible changes after a month of storage, however the natural microflora partially recovered. Planktonic microorganisms in the amount of 2.33 log CFU/mL, as well as biofilms on the walls of the flasks, were detected in a month in the control water samples. The colour of the bottom of the control flasks changed to dirty yellow. In the field, ozonation of water for 10 minutes prevented its spoilage even when the recommended treatment volume was increased by 10 times. The obtained results indicate that electrolytic ozonation is an effective method of freshwater disinfection, and portable ozonators can play an important role in emergency water purification in areas of armed conflicts or natural disasters

Keywords: ozone; water disinfection; inactivation of microorganisms; portable ozone generator; armed conflict

INTRODUCTION

Clean water is an essential resource for both human life and various industries. Military operations can have a significant and detrimental impact on water quality for

residents in active conflict zones due to the destruction of water supply and wastewater infrastructure, including water treatment plants, distribution systems, and sewage

Suggested Citation:

Pyatkovskyy T, Pokryshko O, Danylkov S. Exploring water disinfection through electrolytic ozonation for application in wartime conditions. *Bull Med Biol Res.* 2024;6(1):43–51. DOI: 10.61751/bmbr/1.2024.43

*Corresponding author



facilities. Russia's war against Ukraine has significant environmental consequences [1], especially for Ukrainian water resources [2].

Ensuring access to clean water is of utmost importance for civilians, the military, rescuers, and volunteers in areas with destroyed civilian infrastructure. In emergency water disinfection, the military may resort to chlorine-containing tablet disinfectants. However, as it has been stated by L.B. Cahoon [3] despite their low cost, these disinfectants may not be readily available to the civilian population and could pose risks due to the formation of toxic or carcinogenic chlorination by-products. The formation of disinfection by-products associated with a potential heightened risk of bladder cancer, along with other adverse reproductive health effects, have been reported by M. Lindmark *et al.* [4]. An alternative for emergency water disinfection is the use of ozonation. Ozone is a powerful oxidant with strong antimicrobial properties [5]. D. Zheng *et al.* [6] reported that by its properties, ozone is a stronger oxidizing agent than molecular oxygen or hydrogen peroxide and reacts with most substances at room temperature. C. Chuwa *et al.* [7] documented that ozone can effectively inactivate bacteria, viruses and other pathogens present in water, in fruits, vegetables, meat, grains, and their products. Traditionally, water ozonation involved bubbling ozone gas through water, necessitating the use of costly high-performance industrial ozonators [8] and adherence to safety regulations. As reported by E. Grignani *et al.* [9] gaseous ozone, upon contact, can irritate the eyes, skin, and mucous membranes. Residual gaseous ozone must be neutralised by thermal or catalytic destructors [10]. In addition, the traditional method of creating ozone involved the use of concentrated oxygen, which poses explosive risks. E.I. Epelle *et al.* [11] reported the utilization of electrolysis to saturate water with ozone, bypassing the dangerous gaseous phase. Consequently, there is an urgent need for the development of portable, energy-saving, and, most importantly, safe devices for

water disinfection. These devices are crucial for deployment in wartime, natural disasters, daily life, and within medical and veterinary institutions.

This study focuses on evaluating the effectiveness of such portable devices, utilizing an electrolytic method to saturate water with ozone. Powered by low-voltage (5 V) sources, these devices are designed for emergencies, providing a swift and efficient means of water disinfection. The purpose of this study was to further investigate the effectiveness of electrolytic ozonation for disinfecting fresh water, with a focus on assessing the long-term impact of ozonation on the quality of drinking water.

✦ MATERIALS AND METHODS

This study is a continuation of previous research [12] focused on the disinfection of fresh water by electrolytic ozonation.

Water samples and duration of the experiment. To test the effectiveness of long-term water disinfection with electrolytic ozone, samples of spring water were collected (Hai-Hrechynski village, Ternopil district). Water samples taken on the day of the experiment were collected directly from the stream into sterile 300 mL flasks and then delivered to the laboratory. Some samples were used for short-term experiments (ozone concentration measurements). The other part was left after treatment to study the long-term effect of ozonation (bacteriological and colour analysis). To maximise natural light, the treated and untreated water samples were stored at room temperature ($20 \pm 2^\circ\text{C}$) on the windowsill of an east-facing window for one month (from mid-November to mid-December 2023).

Water treatment conditions. Water ozonation was performed with a commercial portable ozoniser (the manufacturer is not specified at the request of the equipment owner to avoid advertising) by saturating water with ozone obtained by electrolysis [13]. The production scheme and the equation for ozone formation are depicted in Figure 1.

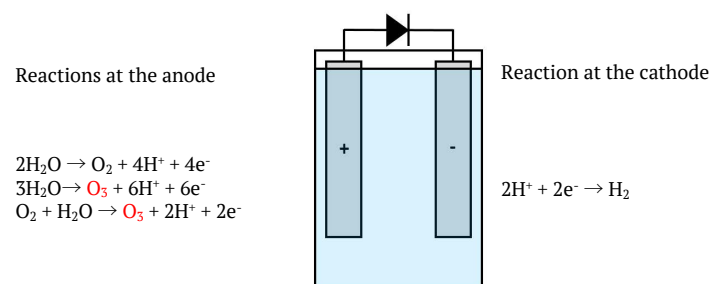


Figure 1. Principle of operation of the ozonator, illustrating chemical transformations

Source: scheme – compiled by the authors. Chemical equations adapted from F. Okada & K. Nay [13]

The manufacturer specifies an initial ozone concentration ranging from 0.8 to 1.3 mg/l, depending on the duration of ozonation. Two modes of electrolytic ozonation of water, lasting 2 and 5 minutes (referred to as Mode 1 and Mode 2), were installed by the manufacturer. In the

experiments measuring ozone concentration dynamics, both ozonation modes were tested. For experiments involving the long-term preservation of water, two modes were applied as well as an ozonation extended to 10 minutes, achieved by repeating the second mode twice. Before

each experiment, the working part of the ozonator was rinsed with sterile distilled water. Disinfectant solutions were avoided to prevent any impact of residual disinfectants on the results. Throughout ozonation, water stirring was employed to ensure uniform ozone saturation.

Measurement of ozone concentration in aqueous solution. The concentration of ozone in water was measured photometrically using a PoolLab 1.0 photometer (Water-i.d., Eggenstein, Germany) by the intensity of the colour change in the reaction with N,N-diethyl-p-phenylenediamine sulfate [11]. The ozone concentration was determined by the absorption of coloured light (wavelengths of 530 and 620 nm) by the sample compared to the untreated sample using the calibration data programmed into the instrument. The photometer used in this study has an ozone measuring range of 0-4 mg/L and uses three wavelengths (530/570/620 nm) to measure the concentration of ozone and other substances in water. Tablet-based reagents were used for measuring ozone concentration, with each measurement taking approximately 3 minutes per sample. To determine ozone concentration, 500 mL of spring water samples were ozonised in individual sterile measuring cups. Measurements were conducted at room temperature (20°C) every 20 minutes for the initial hour, followed by daily measurements until the ozone concentration reached 0 mg/L.

Microbiological study. To assess the efficacy of water disinfection, both treated and untreated (control) water samples were subjected to decimal serial dilutions in sterile 0.9% NaCl solution. Subsequently, aliquots were combined with nutrient agar (Sanimed-M LLC, Kharkiv, Ukraine) that had been melted and cooled to 50°C. For this process, 1 mL of dilutions and undiluted samples were plated in sterile Petri dishes (Sarstedt, Inc., Numbrecht, Germany). Ten to twelve millilitres of nutrient agar, melted using a water bath (Biosan WB-4MS, BioSan SIA, Riga, Latvia), were added to each plate and mixed by gently shaking. Following agar solidification, the plates were incubated at 30°C for 72 hours, after which colony-forming units (CFU) were counted. The study was conducted both at the beginning and the end (1 month) of the experiment.

Colour change analysis. Colour change analysis was employed to evaluate visible signs of water spoilage. For this purpose, water samples in bottles were photographed using a Nikon D3200 camera (Nikon Corporation, Tokyo, Japan) with a Nikon DX 18-55 mm 1:3.5-5.6 lens. The photographic process occurred at the onset and conclusion (after 1 month) of the experiment indoors under artificial lighting from an arc mercury gas-discharge fluorescent lamp. Accurate colour reproduction was ensured by calibrating to the X-Rite ColourChecker Passport palette using the ColourChecker Passport software (X-Rite Inc., Grand Rapids, Michigan, USA). Colour changes in the samples were analysed on a selected 10 × 10-pixel squares using the free online software Image Colour Extract [14] and the obtained values of the dominant colour were expressed in the CIELAB colour space. Here, the parameter “L*” denotes lightness, while “a*” and “b*” denote colours. In this context, “a*” indicates the ratio of the green and

red components of the colour [(-) – green, (+) – red], and “b*” represents the ratio of the blue and yellow components [(-) – blue, (+) – yellow].

The application of water ozonation in “field conditions” by volunteers in southern Ukraine aimed to address the demand for drinking water. In June-July 2023, groups of volunteers in the Kherson region utilised the same portable ozonisers, totalling 20 units, as part of an operation to assist flood victims after occupation forces detonated the Kakhovka hydroelectric power station dam. The water, sourced from artesian wells in the Buchak aquifer, underwent treatment directly in water containers (5-litre PET bottles). Ozonators were powered by portable solar panels or portable chargers (output voltage: 5 V, current: 3 A).

Statistical analysis. All experiments, except for the colour change assay, were conducted in triplicates. The number of CFU was expressed in logarithmic values. The mean values and the standard deviations were calculated ($M \pm sd$) and utilised for statistical purposes. The equality of mean values in two samples was assessed using Student’s t-test. For comparisons among multiple groups, one-way analysis of variance (ANOVA) was employed, using Statistica 8.0 software (StatSoft Inc., Tulsa, Oklahoma, USA). Subsequently, Tukey’s post hoc analysis was conducted to discern differences in mean values. Significance was determined at $p < 0.05$.

Ethics statement. The research protocol for this study was conducted under the principles outlined in the UNESCO [15]. The study design and procedures were approved by the Committee on Bioethics of I. Horbachevsky Ternopil National Medical University (Protocol No. 76, January 15, 2024), and all participants provided informed consent prior to their involvement in the study. Before participation, all volunteers were briefed on the nature and purpose of the study, as well as any potential risks or benefits involved. Measures were taken to ensure the safety and well-being of participants throughout the study, including appropriate training on the use of portable ozonators and access to necessary medical care in the event of any adverse events. Additionally, efforts were made to respect the autonomy and privacy of participants, and their personal information was handled confidentially following ethical guidelines.

★ RESULTS

Measurement of ozone concentration in aqueous solution. The studies revealed variations in the initial ozone concentration compared to the manufacturer’s specifications. Specifically, the utilization of Mode 1 resulted in a solution with an ozone concentration of 0.74 ± 0.04 mg/L, while Mode 2 generated a concentration of 1.72 ± 0.18 mg/L (Fig. 2).

Measurements of ozone concentration every 20 minutes showed a decrease in each subsequent sample. After an hour, the ozone concentration in the water treated for 2 minutes was 0.55 ± 0.05 mg/L ($p < 0.05$), and in the water treated for 5 minutes – 1.53 ± 0.10 mg/L ($p > 0.05$). Subsequent measurements of ozone concentration revealed that it became undetectable in samples treated with Mode 1 by day 2-3, and with Mode 2 by day 4 (Fig. 3).

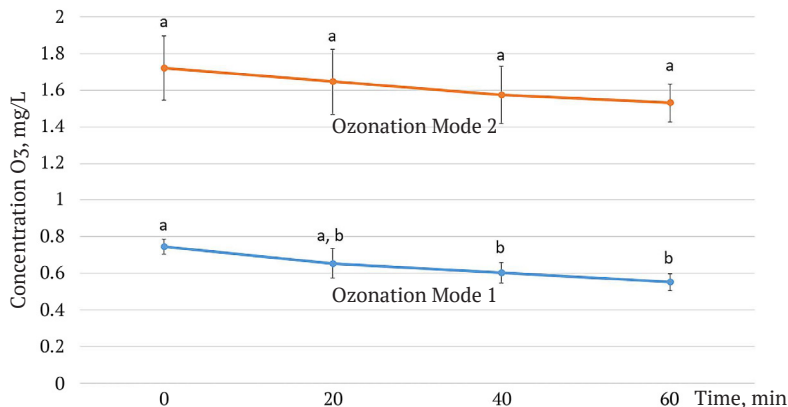


Figure 2. Changes in ozone concentration in aqueous solution after ozonation for 2 and 5 minutes over one hour
Notes: error bars indicate the standard deviation of the mean, and letters above the bars denote a significant difference ($p < 0.05$)
Source: compiled by the authors

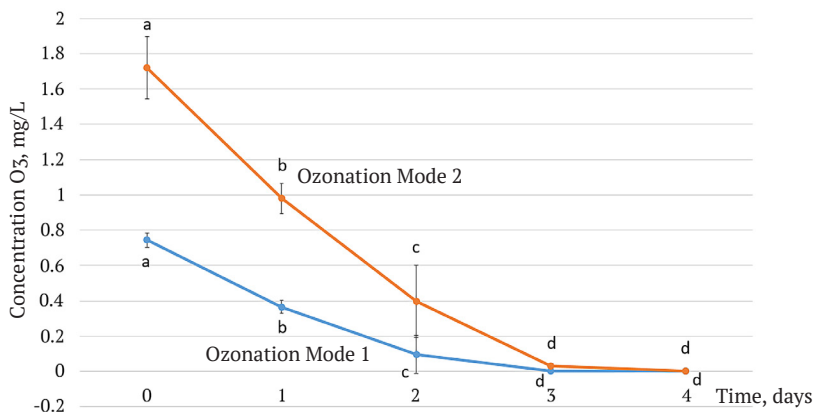


Figure 3. Long-term changes in ozone concentration in aqueous solutions following ozonation for 2 and 5 minutes over a period of several days
Notes: error bars indicate the standard deviation of the mean, and letters above the bars denote a significant difference ($p < 0.05$)
Source: compiled by the authors

After storing the solution at room temperature for a day, the ozone concentration in water treated with Mode 1 was 0.37 ± 0.04 mg/L, while in samples treated with Mode 2, 0.98 ± 0.08 mg/L of ozone remained ($p < 0.05$). Within a day, the ozone concentration decreased to 0.10 ± 0.10 mg/L and 0.40 ± 0.08 mg/L ($p < 0.05$) for samples treated with Mode 1 and Mode 2, respectively. After 3 days, ozone at a concentration of 0.03 ± 0.01 mg/L ($p < 0.05$) was detected only in samples treated with Mode 2. In addition to photometric analysis, the samples were evaluated organoleptically,

revealing that even at low ozone concentrations in water, the samples retained a specific ozone odour.

Microbiological study. Microbiological studies have demonstrated that ozonation significantly diminishes the number of microorganisms in spring water. The total microbial count (TMC) of control samples was 128.7 ± 14.5 (2.11 ± 0.05 log CFU/mL). Following ozonation treatment, only single microorganisms were detected, and this was observed exclusively in samples treated by Mode 1 (Table 1).

Table 1. Microbial counts in water at the start and end of the experiment (log CFU/mL)

Ozonation time	Microbial counts in spring water	
	start of the experiment (day 1)	end of the experiment (day 30)
2 minutes	0.61 ± 0.21	$1.92 \pm 0.26^*$
5 minutes	0	0
10 minutes	0	0
Control	2.11 ± 0.05	$2.33 \pm 0.11^*$

Notes: * – $p < 0.01$
Source: compiled by the authors

Storage of water samples for one month revealed a significant ($p < 0.01$) increase in the number of microorganisms in both control samples and those treated with Mode 1. However, visible signs of water spoilage were observed exclusively in control samples.

Assessment of visible signs of water spoilage. At the beginning of the experiment, the colour analysis revealed that the bottom of all flasks appeared grey. This was attributed to the absence of sediment, the transparency of the

water and glass, and the shadow cast by the flask itself on a white background (Fig. 4).

Storage of water samples for one month revealed visible changes only in the control sample. Colour analysis indicated a shift of the “b*” parameter toward the yellow spectrum, resulting in a noticeable, dirty yellow colour of the sediment at the bottom. In contrast, the colour of the bottom in treated samples retained shades of grey similar to the initial conditions (Fig. 5).

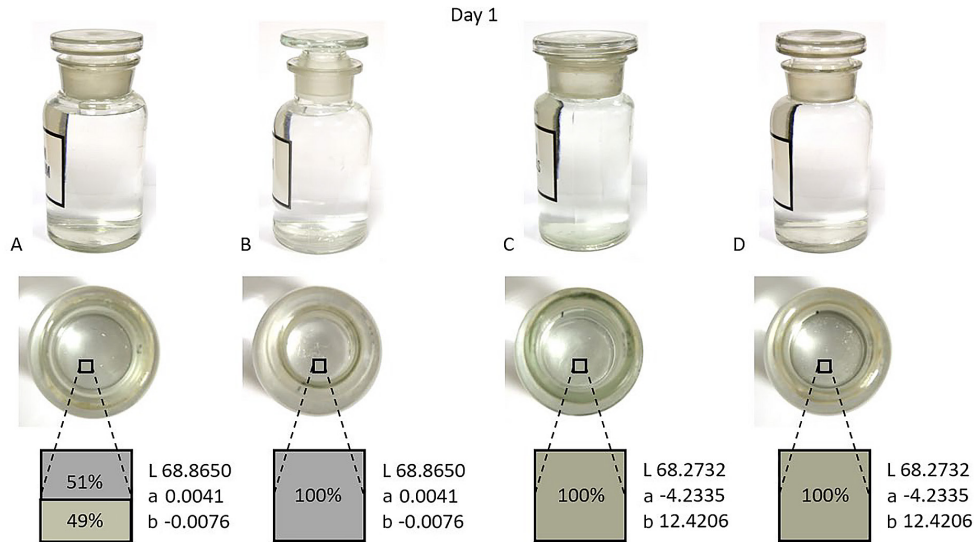


Figure 4. Colour analysis of the bottom of the flasks on the first day of the experiment

Notes: A – untreated sample (control); B – water treated with ozone for 2 minutes; C – water treated with ozone for 5 minutes; D – water treated with ozone for 10 minutes; L – lightness, a – ratio of the green and red components of the colour [(-) – green, (+) – red], b – ratio of the blue and yellow components [(-) – blue, (+) – yellow]

Source: compiled by the authors

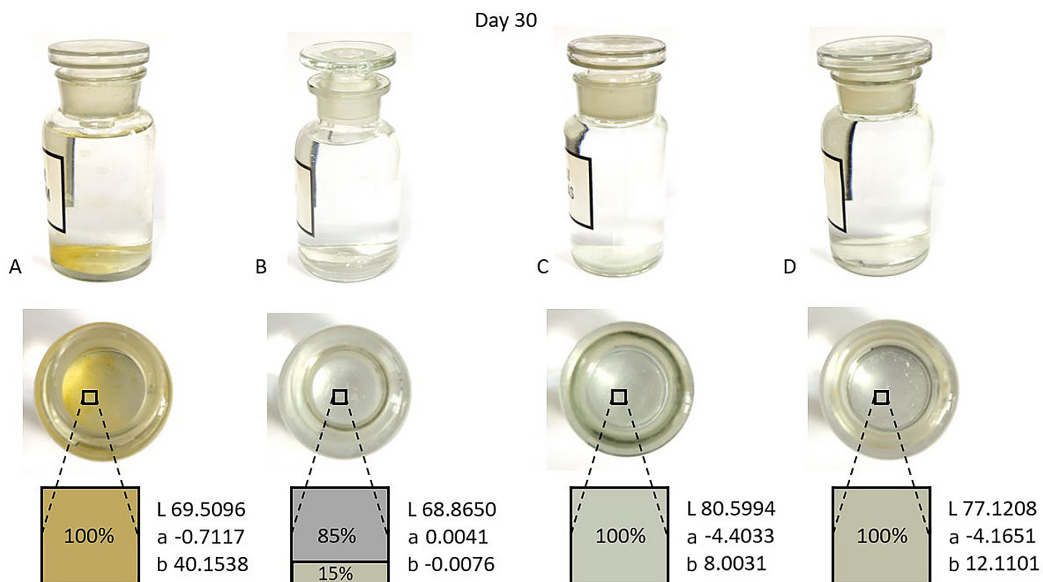


Figure 5. Colour analysis of the bottom of the flasks on the last day of the experiment

Notes: A – untreated sample (control); B – water treated with ozone for 2 minutes; C – water treated with ozone for 5 minutes; D – water treated with ozone for 10 minutes; L – lightness, a – ratio of the green and red components of the colour [(-) – green, (+) – red], b – ratio of the blue and yellow components [(-) – blue, (+) – yellow]

Source: compiled by the authors

Furthermore, after emptying the flasks, biofilms were observed on the walls of the control flask (Fig. 6). Inoculation of material from these formations on nutrient agar revealed bacterial growth. No biofilms were found in the treated water samples.

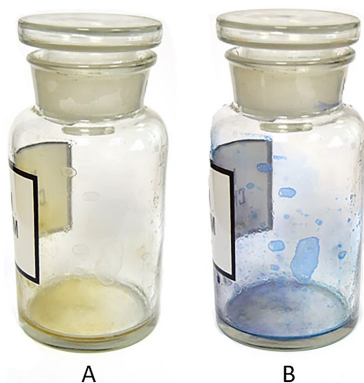


Figure 6. Biofilms on the walls of the flask

Notes: A – after emptying the flask; B – after staining with methylene blue

Source: compiled by the authors

These observations, combined with microbiological studies, affirmed the spoilage of water in the control sample and the preservation of water suitable for consumption in the ozone-treated samples.

The results of the application of water ozonation in “field conditions” by volunteers in southern Ukraine aimed to address the demand for drinking water. In the summer of 2023 (June-July), a group of volunteers in the Kherson region employed portable ozonators for water pretreatment. At times, the ozonators were powered by connecting them to residential electricity lines, but more frequently, the volunteers utilised either solar panels or portable chargers. The utilization of both solar panels and portable chargers afforded the volunteers flexibility, enabling them to operate the ozonators independently of residential electricity grids. The temperature in the Kherson region during these months exceeded 35°C. Water sourced from the Kyiv region (Buchak aquifer) rapidly deteriorated when stored in plastic bottles under warm, sunny conditions. Volunteers observed changes in colour (yellowing, greening) and an unpleasant smell. These alterations were attributed to the proliferation of cyanobacteria (resulting in greening and the development of an odour) [16] and the naturally elevated iron content in the waters of the Buchak aquifer (leading to yellowing) [17]. Upon applying ozonation for 10 minutes with portable ozonators (Mode 2 twice), the water remained potable for 2-4 weeks without visible signs of deterioration before complete use. According to volunteer observations, water that had turned yellow during storage regained its transparency after ozonation, and the unpleasant smell dissipated. The volunteers utilised the ozone-treated water for drinking, cooking, and personal hygiene. It's noteworthy that the volunteers, contrary to manufacturer instructions (which recommend a maximum ozonation volume of 500 mL), used portable ozonators in 5-litre PET bottles, exceeding the recommended volume by ten times.

DISCUSSION

The relatively slow decomposition of ozone was surprising, given that other authors have reported rapid decomposition in aqueous solutions, leading to the formation of molecular oxygen, hydroxyl radicals, and short-lived reactive oxygen species [18, 19]. E.I. Epelle *et al.* [11] reported a half-life of 10 minutes at 18°C for electrolytically produced ozone in drinking water. Similarly, Y. Hirahara *et al.* [18] observed a half-life of 39 minutes for electrolytic ozone in distilled water at 20°C. K. Varol [20] reported a half-life of 20 minutes for ozone in various water types, including ozonated drinking water, distilled water, and water for injection, in studies involving ozonation by bubbling. It's worth noting that M. Seki *et al.* [21] demonstrated a longer storage of ozone in an aqueous solution produced by nanobubble technology. In their research, commercially prepared ozonated water lost 90% of its ozone after a week at 25°C, while at 4°C, it retained 90% of its original concentration over the same time. The findings of the authors mentioned above are consistent with the results described in this manuscript, despite the technical differences in the types of ozonated water studied.

The ozone inactivation of microorganisms in spring water aligns with the findings of L. Meunier *et al.* [22], who demonstrated the inactivation of more than 5 log CFU of vegetative bacterial cells by bubbling an ozone-containing gas mixture through cooled drinking water. In the experiments conducted by the authors of this manuscript, water treated with ozonation for over 5 minutes remained bacteria-free for one month. This is similar to the findings of A.M. Gorito *et al.* [23] who explored the potential of preventing bacterial recovery in water through ozonation, albeit with more contaminated (6 log CFU/100 mL) (Note: units as per the original paper) river water. According to their results, 1.5 mg/L for 10 minutes neutralised all microorganisms, but after storing samples for 3 days at 37°C, live microorganisms were detected. However, increasing the ozone concentration to 3 mg/L prevented the recovery of microorganisms after treatment and storage.

The volunteers' observations regarding the restoration of the transparency of yellowed water align with the findings of T. Zhang *et al.* [24], who described the effective decolourization of water during ozonation by bubbling gaseous ozone (1.5-3 mg/L). The ozonation of municipal wastewater, in conjunction with flocculation, filtration, and ultraviolet treatment, was explored in their study. However, the results indicated limited effectiveness in removing odour-causing substances, prompting the additional recommendation of nanofiltration. X. Ren *et al.* [25] demonstrated a reduction of odour-forming substances (geosmin and 2-methylisoborneol) in open water by over 92% using ozonation by bubbling (2 mg/L) combined with filtration through granular activated carbon. The restoration of the transparency of yellowed water, as described by the volunteers, is consistent with the work of S. Tripathi & T. Hussain [26], who reported the oxidation of iron and manganese in water using ozone. Additionally, both laboratory findings and volunteers' observations are in line with the conclusions of T. Manasfi [27] who stated that while disinfection is frequently the primary objective of using ozone in drinking water treatment, additional applications encompass the removal of colour,

odour, and taste compounds, as well as the elimination of iron and manganese.

The prevention of biofilm formation on surfaces using ozonated water was also observed by M. Marino *et al.* [28]. They reported the inactivation of strains of microorganisms such as *Pseudomonas fluorescens*, *Staphylococcus aureus*, and *Listeria monocytogenes* in biofilms on the surface of stainless steel under both static and dynamic application of ozonised water, produced by the electrolytic method, with an ozone concentration of 0.5 mg/L. Additionally, J.C. Oliver *et al.* [29] observed the effective inactivation of *Pseudomonas aeruginosa* in biofilms on contact lens containers using distilled water saturated with ozone. In contrast, L. Zhang *et al.* [30] reported that stress induced by excessive ozonation resulted in more intensive biofilm accumulation of *Legionella* compared to lower doses of ozone.

The decentralised use of ozonation for water treatment in Western Kenya was detailed by C. Hendrickson *et al.* [31]. In their study, the authors employed solar panels to power ozonators, which sterilised contaminated groundwater stored in a 1000-litre tank. Their system incorporated flocculation and filtration methods prior to ozonation. Similarly to the portability of ozonators described in this manuscript, A. Hafeez *et al.* [32] described the utilization of lightweight (750 gm approximately) portable solar-powered non-thermal air plasma devices which could be fully charged and taken to remote areas or where a power source is not available. The conducted studies, in general, demonstrate the potential of electrolytic ozonation for extending the shelf life of water, both indoors and in the field.

◆ CONCLUSIONS

This study aimed to evaluate the efficiency of freshwater disinfection through electrolytic ozonation, particularly in the context of emergency water purification in areas affected by armed conflicts or natural disasters. The results indicate that electrolytic ozonation effectively pro-

duced aqueous ozone solutions with concentrations suitable for disinfection purposes. Ozonation of 500 mL of spring water through electrolysis for two and five minutes resulted in aqueous ozone solutions with concentrations of 0.74 and 1.72 mg/L, respectively. Electrolytic ozone exhibited gradual decomposition, with detectable levels remaining in the samples three days following the water treatment. Ozonation of water for five and ten minutes successfully inactivated up to 2.11 log CFU/mL of natural microorganisms and prevented spoilage both in laboratory and field conditions, demonstrating its potential for ensuring the safety and availability of clean water in challenging environments. Furthermore, ozonation of water samples prevented the formation of natural flora biofilms, which were observed in control samples. The practical value of this work lies in its contribution to emergency response efforts, where access to clean water is essential for sustaining life and preventing disease outbreaks. By demonstrating the effectiveness of electrolytic ozonation in producing safe drinking water, this study offers a viable solution for addressing water sanitation challenges in resource-constrained settings, including those affected by conflict or disaster. Future research could explore further optimization of electrolytic ozonation processes to enhance efficiency and scalability, as well as investigate the long-term stability and safety of ozonated water. Additionally, studies examining the effectiveness of electrolytic ozone in preventing the formation of biofilms on various surfaces would be highly valuable.

◆ ACKNOWLEDGEMENTS

The authors express their gratitude to the medical centre “Dr. Che health club” for the provided equipment and advice.

◆ CONFLICT OF INTEREST

The authors declare no conflict of interest.

◆ REFERENCES

- [1] Pereira P, Bašić F, Bogunovic I, Barcelo D. Russian-Ukrainian war impacts the total environment. *Sci Total Environ.* 2022;837:155865. DOI: [10.1016/j.scitotenv.2022.155865](https://doi.org/10.1016/j.scitotenv.2022.155865)
- [2] Shumilova O, Tockner K, Sukhodolov A, Khilchevskiy V, De Meester L, Stepanenko S, et al. Impact of the Russia – Ukraine armed conflict on water resources and water infrastructure. *Nat Sustain.* 2023;6:578–86. DOI: [10.1038/s41893-023-01068-x](https://doi.org/10.1038/s41893-023-01068-x)
- [3] Cahoon LB. Water purification: Treatment of microbial contamination. In: *Advances in water purification techniques: Meeting the needs of developed and developing countries.* San Diego: Elsevier Inc.; 2019. Chapter 15; p. 385–95. DOI: [10.1016/B978-0-12-814790-0.00015-6](https://doi.org/10.1016/B978-0-12-814790-0.00015-6)
- [4] Lindmark M, Cherukumilli K, Crider YS, Marcenac P, Lozier M, Voth-Gaeddert L, et al. Passive in-line chlorination for drinking water disinfection: A critical review. *Environ Sci Technol.* 2022;56(13):9164–81. DOI: [10.1021/acs.est.1c08580](https://doi.org/10.1021/acs.est.1c08580)
- [5] Pandiselvam R, Subhashini S, Banuu Priya EP, Kothakota A, Ramesh SV, Shahir S. Ozone based food preservation: A promising green technology for enhanced food safety. *Ozone Sci Eng.* 2019;41(1):17–34. DOI: [10.1080/01919512.2018.1490636](https://doi.org/10.1080/01919512.2018.1490636)
- [6] Zheng D, Huang J, Fang Y, Deng Y, Peng C, Dehaen W. Fluorescent probes for ozone-specific recognition: An historical overview and future perspectives. *Trends Environ Anal Chem.* 2023;38:e00201. DOI: [10.1016/j.teac.2023.e00201](https://doi.org/10.1016/j.teac.2023.e00201)
- [7] Chuwa C, Vaidya D, Kathuria D, Gautam S, Sharma S, Sharma B. Ozone (O₃): An emerging technology in the food industry. *Food Nutr J.* 2020;5:224. DOI: [10.29011/2575-7091.100124](https://doi.org/10.29011/2575-7091.100124)
- [8] Buntasana S, Seankongsuk P, Vilaivan T, Padungros P. Household ozone disinfectant as an alternative ozone generator for ozonolysis of alkenes. *Am J Org Chem.* 2021;10(5):1141–52. DOI: [10.1002/ajoc.202100024](https://doi.org/10.1002/ajoc.202100024)
- [9] Grignani E, Mansi A, Cabella R, Castellano P, Tirabasso A, Sisto R, et al. Safe and effective use of ozone as air and surface disinfectant in the conjuncture of COVID-19. *Gases.* 2021;1(1):19–32. DOI: [10.3390/gases1010002](https://doi.org/10.3390/gases1010002)
- [10] Li X, Ma J, He H. Recent advances in catalytic decomposition of ozone. *J Environ Sci.* 2020;94:14–31. DOI: [10.1016/j.jes.2020.03.058](https://doi.org/10.1016/j.jes.2020.03.058)

- [11] Epelle EI, Macfarlane A, Cusack M, Burns A, Amaeze N, Richardson K, et al. Stabilisation of ozone in water for microbial disinfection. *Environments*. 2022;9(4):45. DOI: [10.3390/environments9040045](https://doi.org/10.3390/environments9040045)
- [12] Pyatkovskyy TI, Pokryshko OV, Danylkov SO. Assessing the effectiveness of ozonation for fresh water disinfection. *Achiev Clin Exp Med*. 2023;(4):113–18. DOI: [10.11603/1811-2471.2023.v.i4.14189](https://doi.org/10.11603/1811-2471.2023.v.i4.14189)
- [13] Okada F, Nay K. Electrolysis for ozone water production. In: Linkov V, Kleperis J, editors. *Electrolysis*. London: IntechOpen; 2012. P. 243–72. DOI: [10.5772/51945](https://doi.org/10.5772/51945)
- [14] Kepler G. Image color extract [Internet]. [cited 2024 Jan 23]. Available from: http://www.coolphptools.com/color_extract
- [15] UNESCO. Universal Declaration on Bioethics and Human Rights [Internet]. [cited 2024 Jan 23]. Available from: <https://www.unesco.org/en/legal-affairs/universal-declaration-bioethics-and-human-rights?hub=66535>
- [16] Vu HP, Nguyen LN, Zdarta J, Nga TTV, Nghiem LD. Blue-green algae in surface water: Problems and opportunities. *Curr Pollut Rep*. 2020;6:105–22. DOI: [10.1007/s40726-020-00140-w](https://doi.org/10.1007/s40726-020-00140-w)
- [17] Shevchenko OL, Bezrodnyi DA. Artificial salinization of the aquifer in Poltava sequence deposits in the village of Tarasivka, Kyiv region. *Geochem Technog*. 2020;4:40–49. DOI: [10.15407/geotech2020.32.040](https://doi.org/10.15407/geotech2020.32.040)
- [18] Hirahara Y, Iwata K, Nakamuro K. Effect of citric acid on prolonging the half-life of dissolved ozone in water. *Food Saf*. 2019;7(4):90–94. DOI: [10.14252/foodsafetyfscj.D-19-00005](https://doi.org/10.14252/foodsafetyfscj.D-19-00005)
- [19] Ziyaina M, Rasco B. Inactivation of microbes by ozone in the food industry: A review. *Afr J Food Sci*. 2021;15(3):113–20. DOI: [10.5897/AJFS2020.2074](https://doi.org/10.5897/AJFS2020.2074)
- [20] Varol K. [Determination of maximum ozone concentrations and half-life of ozone in some drinking water and high-quality pure water produced in new system devices](https://doi.org/10.1007/s11356-022-2285-9). *Fresenius Environ Bull*. 2022;31:2285–94.
- [21] Seki M, Ishikawa T, Terada H, Nashimoto M. Microbicidal Effects of stored aqueous ozone solution generated by nano-bubble technology. *In Vivo*. 2017;31(4):579–83. DOI: [10.21873/invivo.11097](https://doi.org/10.21873/invivo.11097)
- [22] Meunier L, Canonica S, von Gunten U. Implications of sequential use of UV and ozone for drinking water quality. *Water Res*. 2006;40(9):1864–76. DOI: [10.1016/j.watres.2006.02.030](https://doi.org/10.1016/j.watres.2006.02.030)
- [23] Gorito AM, Pesqueira JFJR, Moreira NFF, Ribeiro AR, Pereira MFR, Nunes OC, Almeida CMR, Silva AMT. Ozone-based water treatment (O₃, O₃/UV, O₃/H₂O₂) for removal of organic micropollutants, bacteria inactivation and regrowth prevention. *J Environ Chem Eng*. 2021;9(4):105315. DOI: [10.1016/j.jece.2021.105315](https://doi.org/10.1016/j.jece.2021.105315)
- [24] Zhang T, Tao YZ, Yang HW, Chen Z, Wang XM, Xie YF. Study on the removal of aesthetic indicators by ozone during advanced treatment of water reuse. *J Water Process Eng*. 2020;36:101381. DOI: [10.1016/j.jwpe.2020.101381](https://doi.org/10.1016/j.jwpe.2020.101381)
- [25] Ren X, Wu Q, Shu J, Chen C, Tiraferri A, Liu B. Efficient removal of organic matters and typical odor substances in rural drinking water using Ozone-BAC-UF combined system to meet new water quality standards in China. *Sep Purif Technol*. 2023;327:124899. DOI: [10.1016/j.seppur.2023.124899](https://doi.org/10.1016/j.seppur.2023.124899)
- [26] Tripathi S, Hussain T. Water and wastewater treatment through ozone-based technologies. In: *Development in Wastewater treatment research and processes: Removal of emerging contaminants from wastewater through biotechnology*. Amsterdam: Elsevier; 2022. Chapter 7; p. 139–72. DOI: [10.1016/B978-0-323-85583-9.00015-6](https://doi.org/10.1016/B978-0-323-85583-9.00015-6)
- [27] Manasfi T. Ozonation in drinking water treatment: An overview of general and practical aspects, mechanisms, kinetics, and byproduct formation. *Comprehensive Anal Chem*. 2021;92:85–16. DOI: [10.1016/bs.coac.2021.02.003](https://doi.org/10.1016/bs.coac.2021.02.003)
- [28] Marino M, Maifreni M, Baggio A, Innocente N. Inactivation of foodborne bacteria biofilms by aqueous and gaseous ozone. *Front Microbiol*. 2018;9:2024. DOI: [10.3389/fmicb.2018.02024](https://doi.org/10.3389/fmicb.2018.02024)
- [29] Oliver JC, Bredarioli PAP, Leandro FD, Ferreira CBRJ, Veiga SMOM, Dias ALT. Ozone against *Pseudomonas aeruginosa* biofilms in contact lenses storage cases. *Rev Inst Med Trop Sao Paulo*. 2019;61:e23. DOI: [10.1590/S1678-9946201961023](https://doi.org/10.1590/S1678-9946201961023)
- [30] Zhang L, Graham N, Li G, Zhu Y, Yu W. Excessive ozonation stress triggers severe membrane biofilm accumulation and fouling. *Environ Sci Technol*. 2024;58(13):5899–10. DOI: [10.1021/acs.est.3c10429](https://doi.org/10.1021/acs.est.3c10429)
- [31] Hendrickson C, Oremo J, Akello OO, Bunde S, Rayola I, Akello D, et al. Decentralized solar-powered drinking water ozonation in Western Kenya: An evaluation of disinfection efficacy. *Gates Open Res*. 2020;4:56. DOI: [10.12688/gatesopenres.13138.2](https://doi.org/10.12688/gatesopenres.13138.2)
- [32] Hafeez A, Shamair Z, Shezad N, Javed F, Fazal T, Rehman Su, Bazmi AA, Rehman F. Solar powered decentralized water systems: A cleaner solution of the industrial wastewater treatment and clean drinking water supply challenges. *J Clean Prod*. 2021;289:125717. DOI: [10.1016/j.jclepro.2020.125717](https://doi.org/10.1016/j.jclepro.2020.125717)

Дослідження знезараження води за допомогою електролітичного озонування для застосування в умовах воєнного часу

Тарас П'ятковський

Кандидат медичних наук, доцент
Тернопільський національний медичний університет ім. І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0003-1240-1680>

Олена Покришко

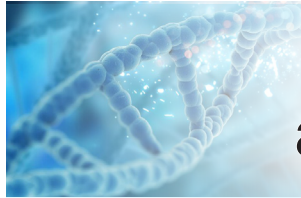
Кандидат медичних наук, доцент
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0001-9640-0786>

Сергій Данилков

Кандидат медичних наук, асистент
Національний медичний університет ім. О. О. Богомольця
01601, бульв. Тараса Шевченка, 13, м. Київ, Україна
<https://orcid.org/0009-0008-7273-4296>

Анотація. Чиста та безпечна вода є фундаментальною вимогою для виживання та добробуту людини. Руйнування цивільної інфраструктури під час воєн чи природних катастроф може сильно обмежити доступ до чистої води для місцевого населення, військових, рятувальників та волонтерів. Метою дослідження було вивчення ефективності знезараження прісної води методом електролітичного озонування. Концентрація озону вимірювали фотометричним способом за інтенсивністю зміни кольору у реакції з N,N-діетил-п-фенілендіаміну сульфатом. Якість води оцінювали мікробіологічно, визначаючи загальне мікробне число зразків, та за допомогою аналізу кольору дна флаконів, у яких зберігалися зразки води. Оцінювали ефективність озонування артезіанської води у польових умовах. Електролітичне озонування 500 мл джерельної води протягом двох та п'яти хвилин створювало водний розчин озону у концентрації 0,74 та 1,72 мг/л відповідно. Озон утворений електролітично розпадався повільно і виявлявся у зразках через три доби після обробки води. Обробка озоном джерельної води протягом 5 та 10 хвилин ефективно знешкоджувала всі природні мікроорганізми ($2,11 \log \text{ КУО/мл}$), вода залишалася стерильною та без змін кольору протягом місяця. При озонуванні протягом 2 хвилин, через місяць видимих змін у зразках не наступало але частково відновлювалася природна мікрофлора. У контрольних зразках через місяць виявлялися планктонні мікроорганізми у кількості $2,33 \log \text{ КУО/мл}$ та біоплівки на стінках флаконів, а колір дна змінювався на брудно-жовтий. В польових умовах озонування води протягом 10 хвилин попереджувало її псування навіть при збільшенні рекомендованого об'єму для обробки у 10 разів. Отримані результати свідчать, що озонування електролітичним способом є ефективним методом знезараження прісної води, а портативні озонатори можуть відігравати важливу роль в екстремому очищенні води в зонах військових конфліктів чи природних катастроф

Ключові слова: озон; знезараження води; інактивація мікроорганізмів; портативний генератор озону; збройний конфлікт



Anthropometric features of limbs in volleyball players of different somatotypes

Larysa Sarafyniuk*

Doctor of Biological Sciences, Professor
National Pirogov Memorial Medical University
21018, 56 Pyrohova Str., Vinnytsia, Ukraine
<https://orcid.org/0000-0001-8253-5997>

Inna Stepanenko

Postgraduate Student
National Pirogov Memorial Medical University
21018, 56 Pyrohova Str., Vinnytsia, Ukraine
<https://orcid.org/0000-0001-5589-4951>

Olha Khapitska

PhD in Medical Sciences, Associate Professor
National Pirogov Memorial Medical University
21018, 56 Pyrohova Str., Vinnytsia, Ukraine
<https://orcid.org/0000-0002-1333-5892>

Olena Lezhnova

PhD in Medical Sciences, Associate Professor
National Pirogov Memorial Medical University
21018, 56 Pyrohova Str., Vinnytsia, Ukraine
<https://orcid.org/0000-0002-1393-3163>

Roman Vlasenko

PhD in Medical Sciences, Lecturer
Vinnytsia National Technical University
21021, 95 Khmelnytske Highway, Vinnytsia, Ukraine
<https://orcid.org/0000-0001-7736-4564>

Abstract. The relevance of determining the anthropometric dimensions of the limbs, which determine the external structure of the human body and have close relationships with the technical and tactical activities of volleyball players, is that morphological characteristics can be the basis for qualified sports selection. The purpose of this study was to determine the differences in the value of anthropometric limb dimensions between volleyball players and girls who did not play sports within the general group and a separate constitutional type. A study was conducted of 108 volleyball players with an average sports experience of 6.361 ± 2.866 years of youthful age (mean age – 18.05 ± 1.39 years). 130 practically healthy girls who did not play sports, of adolescent age (mean age – 17.91 ± 1.49 years) made up the control group. Anthropometry was carried out with certified equipment according to the recommendations of P.P. Shaparenko, somatotyping – by the Carter-Heath method. After determining the constitutional affiliation, volleyball players and non-athletes were divided into four groups: ectomorphic, mesomorphic, ecto-mesomorphic and middle intermediate somatotypes. It was found that all the girth dimensions of the upper and lower extremities and the width of the distal

Suggested Citation:

Sarafyniuk L, Stepanenko I, Khapitska O, Lezhnova O, Vlasenko R. Anthropometric features of limbs in volleyball players of different somatotypes. Bull Med Biol Res. 2024;6(1):52–63. DOI: 10.61751/bmbr/1.2024.52

*Corresponding author



Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (<https://creativecommons.org/licenses/by/4.0/>)

epiphyses of the thigh, lower leg, shoulder, and forearm were significantly larger in female athletes than in girls of the control group. The somatotypological approach modified the nature of the previous results: in volleyball players of all somatotypes compared to girls of control groups of the corresponding type of constitution only the widths of epiphyses of the shoulder and forearm were statistically significantly larger; the width of the distal epiphysis of the lower leg was bigger only in sportswomen of the average intermediate somatotype, and the width of the distal epiphysis of the thigh was bigger in sportswomen of the ecto-mesomorphic and average intermediate types; most of the girth dimensions of the limbs were bigger only in sportswomen of the ectomorphic and average intermediate somatotypes. Thus, volleyball players of each constitutional type have their peculiarities of the structure of limbs, which should be taken into account when creating a morphometric profile of volleyball players and taken into account in sports orientation and prognostication

Keywords: anthropometry; upper and lower limbs; constitutional types; volleyball

◆ INTRODUCTION

The level of sports performance in modern volleyball is so high that to achieve it, athletes must have a whole range of different data that must be at the highest level. In particular, B. Kazakhov & D. Allayarov [1] emphasise the importance of individual indicators of technical and tactical activity of volleyball players for the effectiveness of the competitive activity of the whole team. M.F.K. Hammoodi *et al.* [2] note that in addition to technical and tactical training of volleyball players, special physical fitness plays a leading role in their success, as Y. Yakusheva *et al.* [3] note in their work. The team of authors of Lviv State University of Physical Culture [4] do not deny the importance of the functional state of the athlete's body for the full implementation of his/her technical and tactical skills but emphasise that anthropometric parameters can be the basis for characterizing morphological and functional changes in the body of an athlete engaged in game sports. A comprehensive analysis and consideration of the anatomical and physiological features of the body ensures the training of highly qualified athletes because the peculiarities of the external structure of the athlete's body are a prerequisite for the realization of his/her physical capabilities [5]. And the results of the assessment of anthropometric characteristics will allow compiling profiles of elite athletes in certain sports, which can be used as a training bar for beginners. An analysis of the anthropometric profile and constitutional characteristics of female athletes of the Mexican Olympic team engaged in classical and beach volleyball was carried out [6]. To assess the anthropometric profile of volleyball players, a comprehensive study was conducted, which included the determination of total dimensions and individual partial dimensions, in particular the thickness of skin folds, longitudinal, girth and transverse body dimensions [4], and the authors propose to use the results obtained to monitor the level of training of volleyball players.

The markers of sports selection should include constitutional features of an athlete, which are formed under genetic influence and modified by exogenous factors, among which the specificity of sports activity can be the most significant because it polishes the physique of an individual athlete to its needs [7]. The majority of the analysed studies define the features of the somatotypic profile of volleyball players, in particular, S.K. Noutsos *et al.* [8] determined the value of the components of the somatotype according to the Heath-Carter in the adolescent elite of female volleyball players and noted that it is the specificity of the training activity of female athletes that leads to

changes in their body, which are provided by adaptation processes to specific physical activities. Using somatotyping by Heath-Carter C. Poveda-Loor *et al.* confirm [9] that in athletes, the value of somatotype components, especially muscle and fat, clearly demonstrate sexual dimorphism, therefore, to develop model anthropometric characteristics of athletes of a particular sport is necessary to take into account the factor of gender.

Thus, the work of many scientists has proven the fact that indicators of the external structure of the body affect sports performance and must be taken into account when conducting qualified both prognostic selection to select beginners who have the greatest chance of achieving outstanding results, and confirmatory selection – for intra-team specialization or team recruitment. In addition, the study of anthropometric features of female athletes is of theoretical importance for understanding the general human morphology. However, few studies examine this issue with regard to the ethno-territorial factor. In addition, there is no data on the peculiarities of the structure of the limbs in female athletes who play volleyball professionally but differ in somatotypic characteristics. The aim of the study was to identify the peculiarities of the girth and transverse dimensions of the upper and lower limbs in high-skilled youth volleyball players of different constitutional types.

◆ MATERIALS AND METHODS

From 2018 to 2023, a study was conducted of 147 youth volleyball players (16 to 20 years old) who had been playing the sport for at least 3 years and had achieved high sportsmanship. The athletes played in the following teams: “Bilozgar – Medical University”, “Dobrodiy – Medical University – School of Higher Sportsmanship (SHS)”, student volleyball teams of higher education institutions of Vinnytsia and children's and youth sports schools of Vinnytsia and Kalynivka. All the athletes underwent ultrasound examination of the heart and parenchymal organs, spirometry, electrocardiography and tetrapolar rheography of the chest and extremities. If hypertension, arrhythmias, regurgitation of II-III degrees, myocardial hypertrophy or pathology of parenchymal organs were detected, practically healthy volleyball players were excluded from the group. Thus, the total group of volleyball players who had no deviations in their health status was 108 athletes. The distribution of volleyball players by the level of sportsmanship in percentage terms is shown in Figure 1.

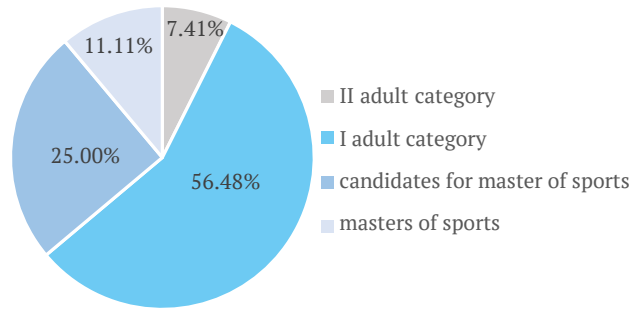


Figure 1. Distribution (%) of volleyball players by level of sportsmanship

Source: developed by the authors

The control group consisted of 130 practically healthy girls of the same age who did not go in for sports. The conclusion about the health status of the girls in this group was made after a comprehensive clinical and laboratory examination (ultrasound examination of the heart, thyroid gland, spleen, kidneys, liver, urinary and gallbladder, X-ray examination; spirometry, electrocardiography, tetrapolar

rheography). In cases of pathology detection, girls were excluded from further research and were not included in the main group of practically healthy. The age distribution of volleyball players and girls of the control group is shown in Table 1, it should be noted that the average age of volleyball players was 18.05 ± 1.39 years, and that of non-athletes – 17.91 ± 1.49 years.

Table 1. Age distribution in the observation groups

Volleyball players (n = 108)			Control group (n = 130)		
Age (years)	Number (n)	%	Age (years)	Number (n)	%
16	20	18.52	16	30	23.08
17	18	16.67	17	30	23.08
18	28	25.92	18	22	16.98
19	20	18.52	19	17	13.08
20	22	20.37	20	31	23.84

Source: developed by the authors

Anthropometry was performed with certified equipment: a caliper was used to determine the width of the distal epiphyses of the tubular bones, a Martin anthropometer – body length, a centimetre tape – girth of the torso and limbs, a caliper – thickness of skin and fat folds, and a medical scale – body weight. The anthropometric study was performed according to the recommendations of P.P. Shaparenko [10]. The somatotypic affiliation was determined by the calculated modification of the Carter-Heath method [11]. After somatotyping, it was found that 28 volleyball players and 33 girls of the control group belonged to the mesomorphic type of constitution. Ectomorphs included 27 volleyball players and 36 control group members; ecto-mesomorphs – 27 volleyball players and 24 control group members, and middle intermediate type – 26 volleyball players and 37 control group members. The results were analysed and graphs were drawn using the licensed software package “Statistica 5.5”. The statistical significance of the difference between the studied groups in the value of anthropometric sizes of extremities was determined by the non-parametric method using the Mann-Whitney U test (the level of statistical significance was estimated by 3 gradations: $p < 0.05$, $p < 0.01$, $p < 0.001$).

The work is a fragment of the planned research work of the Department of Sports Medicine, Physical Education and Rehabilitation of Vinnytsia National Medical University named after M.I. Pirogov “Somato-viscerometric features of the human body in different periods of ontogeny”, state registration number 0121U113772 (applied). The work was approved at the meeting of the Bioethics Committee of the Pirogov National Medical University (Minutes No. 2) on 31 January 2024. The approval process took into account the basic bioethical principles established, in particular, in the Declaration of Helsinki [12].

★ RESULTS

It was established that volleyball players had the widths of distal epiphyses of segments of the upper and lower extremities significantly larger (in all cases $p < 0.001$) than girls of the control group. In particular, the width of a distal epiphysis of a shoulder in volleyball players of mesomorphs is bigger, than in ectomorphs ($p < 0.01$) who had the value of the given size the smallest among all sportswomen, the significant differences ($p < 0.05$) were found at the comparison of volleyball players of ecto-mesomorphic and ectomorphic types (Fig. 2).

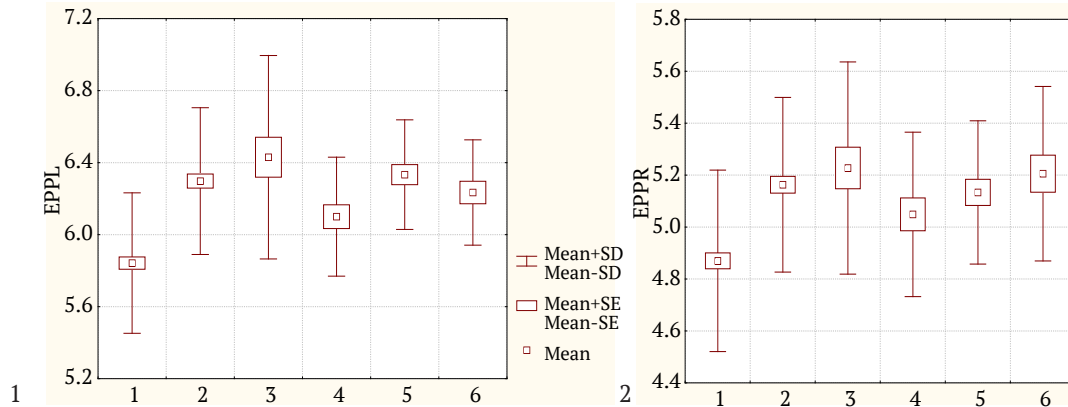


Figure 2. Features of the width of the distal epiphyses

of the shoulder (1) and forearm (2) (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean \pm SE – \pm error of the mean; Mean \pm SD – \pm standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

In order to find out the constitutional conditionality of anthropometric sizes of the upper and lower limb, their size between sportswomen and non-athletes within a separate somatotype was compared. It was found that in volleyball players of all somatotypes (Table 2) the width of the distal epiphysis of the shoulder was greater than in girls of control groups of corresponding constitutional types (in all cases $p < 0.001$). The width of a distal epiphysis

of a forearm had the smallest values in volleyball players of an ectomorphic somatotype, but significant differences between sportswomen of different constitutional types were not revealed (Fig. 2). In volleyball players of mesomorphic ($p < 0.01$), ectomorphic ($p < 0.01$), ecto-mesomorphic ($p < 0.001$) and average intermediate ($p < 0.01$) somatotypes the forearm epiphysis is wider than in control groups (Table 2).

Table 2. Width of the distal epiphyses of limb segments in individuals with different somatotypes ($M \pm \sigma$)

Indicators.	Control	Volleyball players	Control	Volleyball players
	Mesomorphic somatotype		Ectomorphic somatotype	
EPPL	5.765 \pm 0.388	6.430 \pm 0.565***	5.715 \pm 0.437	6.100 \pm 0.330***
EPPR	4.922 \pm 0.324	5.227 \pm 0.409**	4.775 \pm 0.379	5.049 \pm 0.317**
EPB	8.515 \pm 0.375	8.590 \pm 0.806	7.939 \pm 0.407	8.090 \pm 0.744
EPG	6.381 \pm 0.410	6.662 \pm 0.592	6.419 \pm 0.378	6.420 \pm 0.530
	Ecto-mesomorphic somatotype		Middle intermediate somatotype	
EPPL	5.778 \pm 0.254	6.333 \pm 0.304***	5.895 \pm 0.384	6.234 \pm 0.293***
EPPR	4.800 \pm 0.248	5.133 \pm 0.276***	4.899 \pm 0.285	5.206 \pm 0.336**
EPB	8.115 \pm 0.549	8.767 \pm 0.848**	8.102 \pm 0.449	9.136 \pm 0.913***
EPG	6.485 \pm 0.422	6.627 \pm 0.386	6.457 \pm 0.386	6.815 \pm 0.462**

Notes: EPPL – width of the distal epiphysis of the upper arm (cm); EPPR – width of the distal epiphysis of the forearm (cm); EPB – width of the distal epiphysis of the thigh (cm); EPG – width of the distal epiphysis of the lower leg (cm); * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$

Source: developed by the authors

In volleyball players of ectomorphic somatotype the width of the distal femoral epiphysis was less than in sportswomen of mesomorphic ($p < 0.05$), ecto-mesomorphic ($p < 0.01$) and average intermediate ($p < 0.001$) types (Fig. 3). It was found that in non-athletes and volleyball players of mesomorphic and ectomorphic types, there was

no significant difference ($p > 0.05$) in the width of the distal femur epiphysis; and in volleyball players of ecto-mesomorphic ($p < 0.01$) and average intermediate ($p < 0.001$) types of constitution this anthropometric size was larger compared to girls who did not engage in sports of the same constitution (Table. 2).

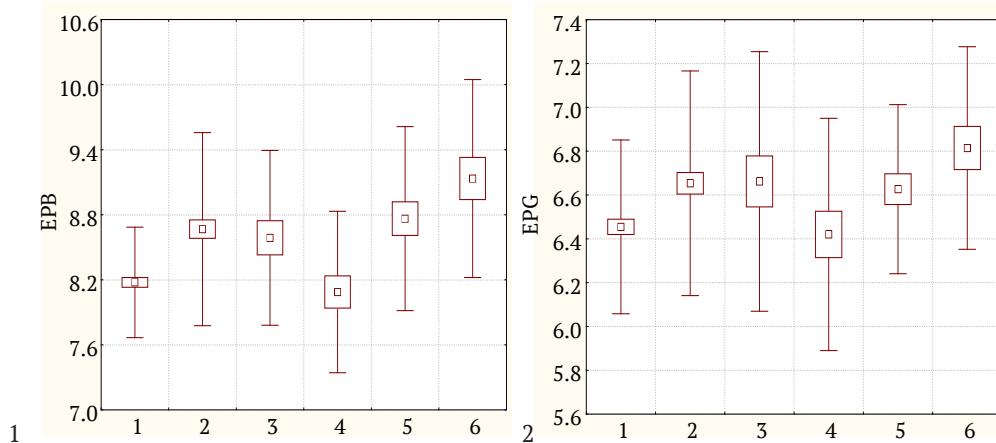


Figure 3. Features of the width of the distal epiphyses

of the thigh (1) and tibia (2) (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean \pm SE – \pm error of the mean; Mean \pm SD – \pm standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

It was established that the width of a distal epiphysis of a tibia had the greatest values in volleyball players of the average intermediate somatotype, and the smallest – in ectomorphs, only between these groups the significant difference ($p < 0.01$) was revealed by the value of this index (Fig. 3). In girls of mesomorphic, ectomorphic and ecto-mesomorphic somatotypes the width of the distal epiphysis of the tibia did not have significant differences depending on the level of motor activity, only in volleyball players of the average intermediate type it was greater ($p < 0.01$) compared to non-athletes of the same type of body constitution (Table 2).

Comparing the value of all girth sizes of segments of the lower and upper extremities between volleyball

players of the general group and non-athletes, we found significantly higher ($p < 0.01$) values in sportswomen. In particular, it concerns the value of shoulder girth in the relaxed and tense states. In addition, volleyball players of mesomorphic somatotype had girths of the tense and relaxed shoulder statistically significantly larger in comparison with ectomorphic volleyball players (in both cases $p < 0.001$) and ecto-mesomorphs ($p < 0.01$ and $p < 0.05$), volleyball players of the average intermediate somatotype had larger shoulder perimeters than ectomorphs (in both cases $p < 0.001$). It was found that volleyball players of ecto-mesomorphs in comparison with ectomorphs had bigger girths of the tense ($p < 0.01$) and relaxed shoulder ($p < 0.05$) (Fig. 4).

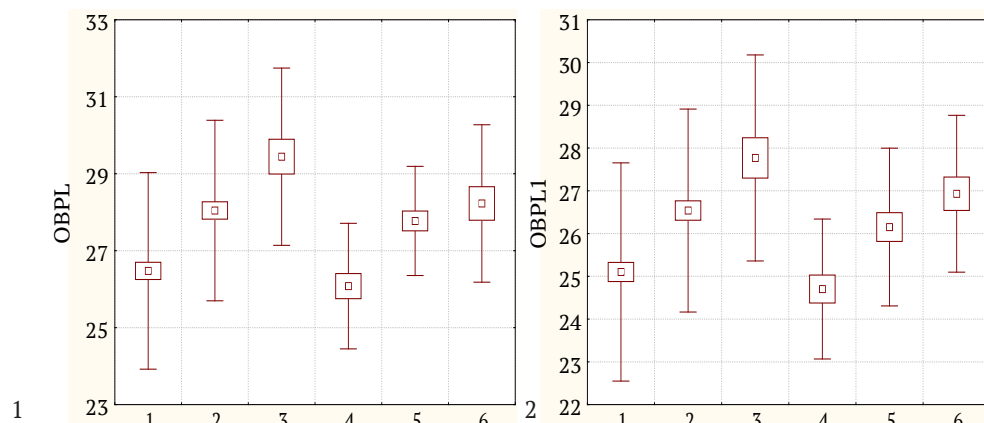


Figure 4. Features of the girth dimensions of the tense (1)

and relaxed (2) shoulder (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean \pm SE – \pm error of the mean; Mean \pm SD – \pm standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

It has been established that in girls with good development of the mesomorphic component of somatotype

(mesomorphs and ecto-mesomorphs) the differences in the size of the girths of the tense and relaxed shoulder

between the groups of sportswomen and non-athletes are levelled. Only volleyball players of ectomorphic and average intermediate types of a body constitution had

bigger shoulder circumferences (in all cases $p < 0.001$) than girls of the control group of the same somatotype (Table 3).

Table 3. Limb circumferences in individuals with different somatotypes (cm, $M \pm \sigma$)

Showcasing. ki	Control	Volleyball players	Control	Volleyball players
	Mesomorphic somatotype		Ectomorphic somatotype	
OBPL	28.20 ± 2.14	29.44 ± 2.30	23.70 ± 1.73	26.08 ± 1.63***
OBPL1	26.97 ± 2.32	27.77 ± 2.41	22.42 ± 1.62	24.70 ± 1.64***
OBPR1	24.04 ± 1.93	24.65 ± 1.28	21.41 ± 1.17	22.86 ± 1.42***
OBPR2	15.88 ± 0.73	15.89 ± 0.93	14.79 ± 0.90	15.38 ± 0.71**
OBB	53.63 ± 4.01	56.02 ± 2.69*	47.84 ± 3.06	50.88 ± 3.19**
OBG1	35.82 ± 2.09	37.85 ± 2.73**	32.00 ± 1.83	34.04 ± 1.65***
OBG2	23.29 ± 1.52	23.39 ± 1.49	21.45 ± 1.08	21.84 ± 1.99
OBK	18.56 ± 1.29	19.14 ± 0.87**	17.85 ± 1.13	18.48 ± 0.80*
OBS	22.64 ± 1.21	23.23 ± 1.13	21.76 ± 1.21	22.73 ± 0.92***
	Ecto-mesomorphic somatotype		Middle intermediate somatotype	
OBPL	26.55 ± 2.12	27.77 ± 1.42	26.04 ± 1.51	28.23 ± 2.05***
OBPL1	25.02 ± 1.95	26.15 ± 1.84	24.50 ± 1.20	26.93 ± 1.83***
OBPR1	23.02 ± 1.28	23.87 ± 1.07	22.82 ± 0.98	24.46 ± 1.38***
OBPR2	15.44 ± 0.99	15.87 ± 0.79	15.68 ± 1.42	16.30 ± 1.05*
OBB	52.29 ± 3.65	54.70 ± 3.19*	51.83 ± 2.59	55.46 ± 3.45***
OBG1	34.47 ± 2.23	36.09 ± 1.65**	34.13 ± 1.72	36.34 ± 1.84***
OBG2	22.66 ± 1.87	22.52 ± 1.39	22.17 ± 1.29	22.68 ± 1.94
OBK	18.42 ± 1.24	18.85 ± 0.69	18.31 ± 0.82	19.23 ± 1.48**
OBS	22.73 ± 1.13	23.25 ± 0.88	22.32 ± 1.12	22.96 ± 1.27

Notes: OBPL: upper arm circumference at rest; OBPL1: upper arm circumference at rest; OBPR1: upper arm circumference at rest; OBPR2: lower arm circumference at rest; OBB – hip circumference; OBG1 – upper leg circumference; OBG2 – lower leg circumference; OBK – hand circumference; OBS – foot circumference; * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$

Source: developed by the authors

The forearm girth in the upper third (Fig. 5) of sportswomen of the general group and mesomorphic, ecto-mesomorphic and average intermediate somatotypes is significantly bigger in comparison with girls of the control group, besides, in volleyball players of mesomorphic and average intermediate somatotype this size is significantly bigger ($p < 0.001$), than in volleyball players of ectomorphs, in whom it is smaller in comparison with ecto-mesomorphs ($p < 0.01$). It was found that mesomorphic volleyball players had a larger ($p < 0.05$) forearm circumference in the upper third than sportswomen of ecto-mesomorphic somatotype. The forearm circumference in the lower third had the highest average values in volleyball players with an average intermediate somatotype, the lowest – in ectomorphs. Significant differences were found when comparing sportswomen of ectomorphs with volleyball players of average intermediate ($p < 0.01$) and

ecto-mesomorphic ($p < 0.05$) somatotypes (Fig. 5). It was established that between volleyball players and non-athletes of mesomorphic and ecto-mesomorphic somatotypes there is no significant difference in the size of the forearm circumference in the upper and lower thirds. Sportswomen of the ectomorphic somatotype had bigger values of forearm circumferences in the upper ($p < 0.001$) and lower ($p < 0.01$) parts than girls of control groups. In volleyball players with an average intermediate somatotype these anthropometric sizes were also significantly larger (Table 3).

It was found that in volleyball players of ectomorphs the hip circumference was significantly smaller (in all cases $p < 0.001$) compared to sportswomen of mesomorphic, ecto-mesomorphic and middle intermediate somatotypes; representatives of other somatotypes practically did not differ among themselves by the value of this indicator (Fig. 6).

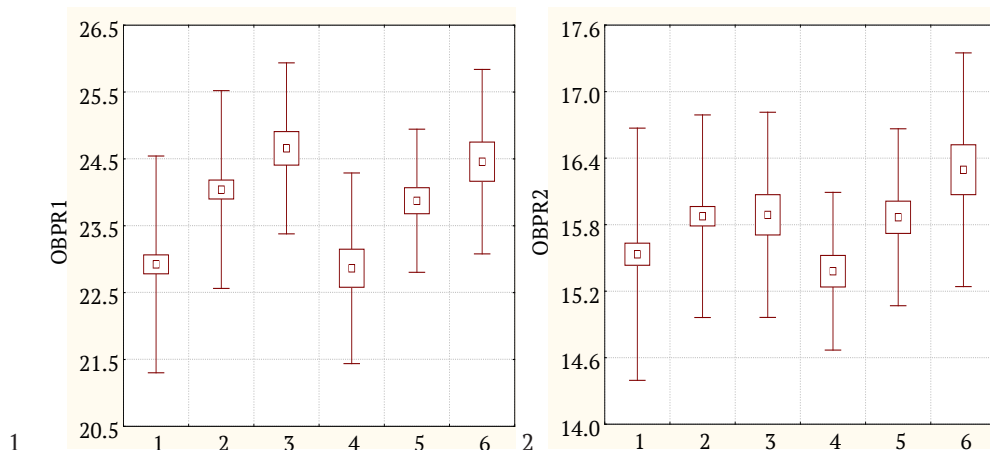


Figure 5. Features of forearm girth dimensions in the upper (1) and lower (2) thirds (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean ± SE – ± error of the mean; Mean ± SD – ± standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

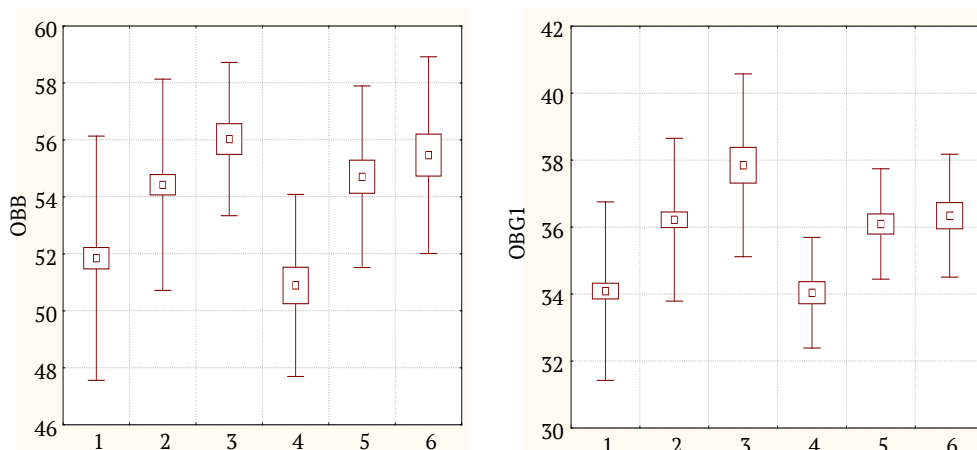


Figure 6. Features of the girth dimensions of the thigh (1)

and lower leg in the upper (2) and lower (3) parts (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean ± SE – ± error of the mean; Mean ± SD – ± standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

The tibia girth in the upper third of volleyball players of mesomorphic somatotype was statistically significantly larger compared to representatives of ectomorphic ($p < 0.001$) and ecto-mesomorphic ($p < 0.05$) somatotypes. In volleyball players of ectomorphs this size was the smallest, therefore significant differences were found when comparing with sportswomen of ecto-mesomorphic and average intermediate somatotypes (in both cases $p < 0.001$) (Fig. 6). It was established that the girths of a thigh and a lower leg in the upper part of sportswomen of the general group (Fig. 6) and all constitutional types were statistically significantly bigger than in girls of control groups (Table 3).

The lower third tibia girth was the smallest in the group of sportswomen of ectomorphic type of a body structure, the significant difference ($p < 0.01$) was established between them and volleyball players of mesomorphic

somatotype in which the average value of this size was the largest among all comparison groups. In volleyball players of mesomorphic somatotype this index was bigger ($p < 0.05$) than in sportswomen of ecto-mesomorphic somatotype (Fig. 7); volleyball players of all constitutional types had this anthropometric size statistically significantly bigger in comparison with non-athletes of control groups of corresponding somatotypes (Table 3).

The girth dimensions of the hand and foot in general groups of volleyball players were significantly larger compared to girls who did not engage in sports (Fig. 8). In volleyball players of ectomorphic somatotype, the hand girth was smaller than in mesomorphic and average intermediate types (in both cases $p < 0.05$). The foot girth did not significantly differ between sportswomen of different constitutional types (Fig. 8).

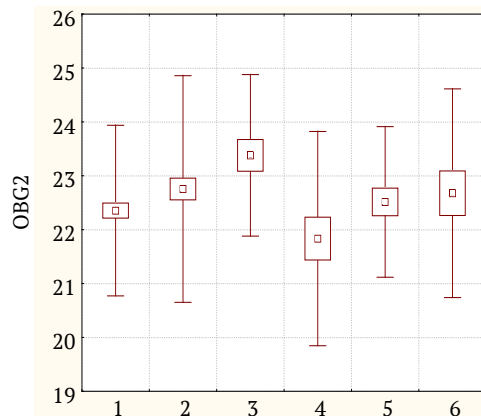


Figure 7. Peculiarities of lower leg girth in the lower part (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean \pm SE – \pm error of the mean; Mean \pm SD – \pm standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

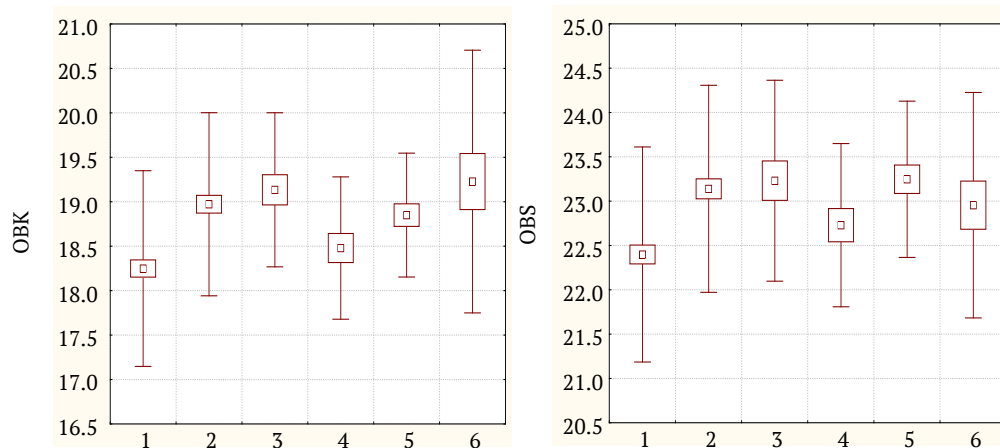


Figure 8. Features of the girth dimensions of the hand (1) and foot (2) (cm) in volleyball players of different somatotypes

Notes: Mean – sample mean; Mean \pm SE – \pm error of the mean; Mean \pm SD – \pm standard deviation; 1 – non-athletes (control group); 2 – general group of volleyball players; 3 – mesomorphic athletes; 4 – ectomorphic athletes; 5 – ecto-mesomorphic athletes; 6 – athletes of intermediate somatotype

Source: developed by the authors

The hand girths of volleyball players of mesomorphic ($p < 0.01$), ectomorphic ($p < 0.05$) and average intermediate ($p < 0.01$) somatotypes are bigger than those of non-athletes of the same somatotype, only representatives of ecto-mesomorphic type did not have significant differences. The average values of a foot girth in volleyball players of all somatotypes were bigger than in non-athletes, but only between sportswomen and girls of the control group of an ectomorphic somatotype the significant differences were revealed ($p < 0.001$) (Table 3). In general, volleyball increases the width of the limb epiphyses and arm and leg circumferences in women, and the effect depends on their body type.

DISCUSSION

In order to achieve a high result, athletes must have an appropriate level of motor skills' development, technical, tactical, game, functional, psychological, and integral

training, which must be at the highest level [1-3]. The combination of these qualities, even with the best planning of the training process in its various cycles at all stages of long-term training, compliance with all the principles of management and control is extremely rare. T. Kutseryb *et al.* [13] note that sports selection should be based on the correspondence of anatomical and physiological features of people to the professional demands of their sports activity. But P.D. Fabricant *et al.* [14] emphasize that early sports specialisation in children and adolescents trying to achieve elite status may be accompanied by an increased risk of injury. According to some scientists, when conducting sports selection, preference should be given to those athletes who have a set of morphological and functional characteristics that significantly affect performance and at the same time have a high degree of genetic determination [15]. Among such morphogenetic traits that affect sports abilities,

anthropometric indicators play an important role [16]. In particular, R. Pavlović [5] notes that such anthropometric parameters as length and body weight can be predictors of sports results in short-distance running, especially at 100 m and 200 m, because it is at these distances that the running performance will depend on the motor-functional ability of the sprinter. Scientists argue that even in team sports, performance may depend on the anthropometric dimensions of the players' bodies [17, 18]. M. Gusic *et al.* [19] argue that representatives of individual game sports differ significantly from each other, have specific anthropometric characteristics, and that football and handball players, in particular, differ significantly in length, body weight, shoulder, forearm and lower leg circumferences. There are few data on anthropometric features of volleyball players of high skill level of a separate period of ontogenesis. In particular, M. Joksimovic *et al.* [20] studied the morphological characteristics of elite volleyball players from 4 different national teams that competed in the European Championship qualifiers, and R. Pavlović *et al.* [21] emphasise the lack of information on the population of volleyball players who compete in top-level competitions. As a result of the present study, it was found that volleyball players had distal epiphysis widths of all segments of the upper and lower extremities significantly larger than girls of the control group. This corresponds to the data obtained by T. Kutseryb *et al.* [4] and S.K. Noutsos *et al.* [8].

The analysis of the literature data did not reveal any works that would study the issue of peculiarities of anthropometric parameters of the lower and upper limbs in volleyball players of different somatotypes. Some scientists [13] also note that there are very few modern works that study the structure of the body of athletes from the point of view of constitutional morphology, comparing somatotypes in athletes of different sports. The use of various methods of somatotyping complicates the analysis and comparison of the obtained somatotypic data in athletes. From our point of view, the use of the method of determination of constitutional types by Hit-Carter is the most objective, because it is based on a number of anthropometric measurements; it gives the chance of individual determination of components of a somatotype in points (digital expression) and due to the presence of intermediate types it is possible to assign each person to a specific constitutional type [11]. In addition, the analysis of modern literature shows that this method is the most common [4, 8, 9]. The use of the Heath-Carter methodology allowed the team of authors Z. Grgantov *et al.* [22] to recommend the use of somatotyping as a selection criterion for young volleyball players of different sports roles (connectors, attackers, libero), noting that most often a balanced ectomorphic somatotype was found in all positions of players.

In conformity with the results of this study, it was found that the somatotypic approach in comparing the transverse dimensions of the limbs confirmed the previously identified (between general groups of comparisons) tendency of a greater width of the distal epiphyses in volleyball players compared to non-athletes of the corresponding constitutional types. But reliable differences were established only for the width of the epiphyses of the shoulder and forearm – in volleyball players of all somatotypes they were statistically significantly larger.

The transverse dimensions of the thigh were significantly larger only in volleyball players of ecto-mesomorphic and middle intermediate somatotypes; in representatives of extreme somatotypes (mesomorphic and ectomorphic) the differences were insignificant. And the width of the distal tibia epiphysis only in volleyball players of the middle intermediate type was significantly larger, between the athletes and the control group of mesomorphic, ectomorphic and ecto-mesomorphic somatotypes the width of the tibia did not differ. Based on this, it can be assumed that belonging to one constitutional type reduces the difference in the size of the transverse dimensions of the lower limb and is a more significant determinant than the peculiarities of sports activity. In addition, the significance of constitutionality is indicated by the fact that significant differences in the size of the transverse dimensions of the limbs between volleyball players belonging to different somatotypes were found. Thus, in sportswomen of mesomorphic somatotype the width of distal epiphyses of a shoulder and forearm was the largest, in ectomorphs – the smallest. Volleyball players of the ectomorphic somatotype had the smallest sizes of diaphyses on the lower limb, and the greatest width of the thigh and tibia was in sportswomen of the middle intermediate somatotype. Earlier it was established [23] that volleyball players of all somatotypes in comparison with non-athletes of corresponding types of constitution had significantly larger almost all transverse sizes of a chest, only width of shoulders statistically did not differ between volleyball players and control groups.

S.S. Karatieieva *et al.* [24], studying the hip circumferences of students involved in sports, faced the problem of the lack of a methodology that would allow the use of circumferential partial parameters as criteria for sports selection in a particular sport. The analysis of scientific research revealed a number of studies that determined the girth dimensions of volleyball players. In particular, A. Pastuszek *et al.* [25] found that volleyball players had larger arm and lower leg circumferences, and J.B. Fields *et al.* [26] reiterate that successful volleyball, like other sports, requires a combination of anthropometric characteristics and technical and tactical indicators.

According to the results of this study, it was found that volleyball players of the general group compared to girls of the control group had larger girth sizes of the upper and lower limbs, which is confirmed by scientific observations on the importance of the development of the muscular system for the sports achievements of volleyball players, so the girth size of the body can be an indicator of a number of elements of motor fitness, as stated by A. Sieroń *et al.* [27].

The somatotypological approach in comparing the size of the circumferences of segments of the upper and lower limbs made it possible to assert that the belonging of adolescent girls to types of constitutions with good development of the mesomorphic component levelled the difference in the size of most of the girth dimensions of the limbs. The only exception was volleyball players of ectomorphic and average intermediate somatotypes, whose sizes were larger compared to girls who did not play sports of the corresponding constitutional types. Regarding somatotypic differences between volleyball players themselves, the prevalence of most girth dimensions, except for the hand and foot circumference, was determined in

sportswomen with mesomorphic somatotype. Volleyball players of ectomorphic somatotype had the smallest average values of these indicators.

Thus, the specificity of training and competitive activity in volleyball is reflected in changes in the external structure of the body, in particular in the anthropometric dimensions of the limbs. It is the transverse and girth parameters of the upper and lower limbs that should be included in the model characteristics of volleyball players, which is necessary for sports selection. Belonging to a certain constitutional type influences the features of girth and transverse dimensions of limbs in volleyball players of high level of sports skill, which also needs to be taken into account in sports specialization.

◆ CONCLUSIONS

The results of the study, which was conducted in volleyball players of different constitutional types and was based on the use of anthropometric and statistical research methods, ensured the fulfilment of the goal in full. Systematic volleyball training has a significant impact on the somatometric features of the upper and lower extremities, as evidenced by the presence of significant differences in the value of these indicators between groups of volleyball players and non-athletes. In addition, genetically determined constitutional features determine the size of the girth and transverse dimensions of the limbs in volleyball players of a high level of sportsmanship. It has been established that volleyball players of the general group in comparison with girls of the control group had larger ($p < 0.01-0.001$) all transverse and girth dimensions of the upper and lower limbs.

Analysing the features of anthropometric sizes within a separate somatotype between sportswomen and non-athletes, it was found that the width of distal epiphyses of the

shoulder and forearm in volleyball players of all somatotypes was larger compared to non-athletes of control groups. The transverse sizes of segments of the lower limb differed only in representatives of separate somatotypes: the width of the distal epiphysis of the lower leg was greater ($p < 0.01$) only in volleyball players of the middle intermediate somatotype, and the width of the distal epiphysis of the thigh was significantly greater in sportswomen of ecto-mesomorphic and middle intermediate types compared to girls of control groups of the same somatotype.

Most of the limb circumferences were larger only in sportswomen of ectomorphic and average intermediate somatotypes compared to girls who did not engage in the corresponding constitutional types. Belonging to constitutional types with good development of the mesomorphic component, levelled the difference between volleyball players and non-athletes in the size of the circumferences of individual segments of the lower and upper extremities.

Further study of the peculiarities of anthropometric dimensions of the lower and upper extremities in volleyball players will allow forming their morphological portrait, which can be the basis for qualified sports selection, taking into account not only intra-team specialization, but also the belonging of athletes to a certain constitutional type. In addition, the size of the limbs, along with other anthropometric indicators of the body, can be the basis for further mathematical modelling of the proper parameters of peripheral haemodynamics in volleyball players of a particular constitutional type.

◆ ACKNOWLEDGEMENTS

None.

◆ CONFLICT OF INTEREST

The authors declare no conflict of interest.

◆ REFERENCES

- [1] Kazakhov B, Allayarov D. [Assessment and interpretation of attacking actions in volleyball](#). *Tex J Multidiscip Stud.* 2022;7:11–13.
- [2] Hammoodi MFK, Shlonska O, Borysova O, Imas Y, Gamalii V, Viktoriia N, Yakusheva Y. Control of special physical training for qualified female volleyball players of different game roles. *Acta Kinesiologica.* 2022;16(1):8. DOI: [10.51371/issn.1840-2976.2022.16.1.8](#)
- [3] Yakusheva Y, Sotskiy K, Burtova O. The structure of competitive activity of highly qualified volleyball players. *Sports Games.* 2023;(3):101–9. DOI: [10.15391/si.2021-3.11](#)
- [4] Kutseriyb T, Hrynkiw M, Vovkanych L, Muzyka F, Melnyk V. Anthropometric characteristic and body composition of female students involved in volleyball training. *Anthropol Rev.* 2023;85(4):31–42. DOI: [10.18778/1898-6773.85.4.03](#)
- [5] Pavlović R. The importance of Reaction Time in Athletics: Influence on the Results of Sprint Runs of World Championships Finalists. *Cent Eur J Sport Sci Med.* 2021;34:53–65. DOI: [10.18276/cej.2021.2-05](#)
- [6] D'Anastasio R, Milivojevic A, Cilli J, Icaro I, Viciano J. Anthropometric profiles and somatotypes of female volleyball and beach volleyball players. *Int J Morphol.* 2019;37(4):1480–85. DOI: [10.4067/S0717-95022019000401480](#)
- [7] Khavtur V, Fedoniuk L, Sarafyniuk L, Khapitska O, Kovalchuk O. Simulation of appropriate rheovasographic indicators of the femur in volleyball players of ectomorphic somatotype depending on anthropometric features. *Wiad Lek.* 2022;75(1 Pt 2):275–80. DOI: [10.36740/WLek202201222](#)
- [8] Noutsos SK, Meletakos GP, Bayios AI. Morphological characteristics of adolescent elite female handball and volleyball players. *J Phys Educ Sport.* 2019;19(Suppl 4):1502–7. DOI: [10.7752/jpes.2019.s4217](#)
- [9] Poveda-Loor C, Yaguachi-Alarcón R, Espinoza-Burgos Á, Frias-Toral E, Suárez R. Dietary intake, anthropometric profile and somatotype in university athletes: Differences between gender and sports practiced. *Mediterr J Nutr Metab.* 2023;16(4):335–52. DOI: [10.3233/MNM-230065](#)
- [10] Shaparenko P. Anthropometry. Vinnytsya: Printing House of M.I. Pirogov Vinnytsia State Medical University; 2000. 71 p.
- [11] Carter JEL, Heath BH. [Somatotyping – development and applications](#). Cambridge: University Press; 1990. 503 p.

- [12] The World Medical Association. Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects [Internet]. [cited 2024 Jan 12]. Available from: <https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/>
- [13] Kutseryb T, Hrynkyv M, Vovkanych L, Muzyka F. [Body proportions and somatotype of female basketball players](#). Sport Sci Ukraine. 2018;87(5):20–24.
- [14] Fabricant PD, Lakomkin N, Sugimoto D, Tepolt FA, Straccolini A, Kocher MS. Youth sports specialization and musculoskeletal injury: A systematic review of the literature. Phys Sportsmed. 2016;44(3):257–62. DOI: [10.1080/00913847.2016.1177476](https://doi.org/10.1080/00913847.2016.1177476)
- [15] Myer GD, Jayanthi N, Difiore JP, Faigenbaum AD, Kiefer AW, Logerstedt D, Micheli LJ. Sport specialization, part I: Does early sports specialization increase negative outcomes and reduce the opportunity for success in young athletes? Sports Health. 2015;7(5):437–42. DOI: [10.1177/1941738115598747](https://doi.org/10.1177/1941738115598747)
- [16] Pietraszewska J, Burdukiewicz A, Stachon A, Andrzejewska J, Pietraszewski B. [Anthropometric characteristics and lower limb power of professional female volleyball players](#). S Afr J Res Sport, Phys Educ Recreat. 2015;37(1):99–12.
- [17] Guimarães E, Baxter-Jones A, Maia J, Fonseca P, Santos A, Santos E, et al. The roles of growth, maturation, physical fitness, and technical skills on selection for a Portuguese under-14 years basketball team. Sports. 2019;7(3):61. DOI: [10.3390/sports7030061](https://doi.org/10.3390/sports7030061)
- [18] Guimarães E, Ramos A, Janeira MA, Baxter-Jones ADG, Maia J. How does biological maturation and training experience impact the physical and technical performance of 11–14-year-old male basketball players? Sports. 2019;7(12):243. DOI: [10.3390/sports7120243](https://doi.org/10.3390/sports7120243)
- [19] Gusic M, Popovic S, Molnar S, Masanovic B, Radakovic M. [Sport-specific morphology profile: Differences in anthropometric characteristics among elite soccer and handball players](#). Sport Mont. 2017;15(1):3–6.
- [20] Joksimovic M, Goranovic K, Petkovic J, Badau D, Hantanu CG. [Morphological characteristics of elite female volleyball players under 19](#). Int J Morphol. 2023;41(4):1203–8.
- [21] Pavlović R, Savić V, Tadić D, Milićević L. Anthropometric characteristics structure of “VC Jahorina” pale volleyball players. Am J Sports Sci Med. 2022;10(1):17–24. DOI: [10.12691/ajssm-10-1-4](https://doi.org/10.12691/ajssm-10-1-4)
- [22] Grgantov Z, Padulo J, Milić M, Ardigò LP, Erceg M, Cular D. Intra-positional and inter-positional differences in somatotype components and proportions of particular somatotype categories in youth volleyball players. Ann Appl Sport Sci. 2017;5(2):37–49. DOI: [10.18869/acadpub.aassjournal.5.2.37](https://doi.org/10.18869/acadpub.aassjournal.5.2.37)
- [23] Sarafyniuk L, Pivtorak V, Khavtur V, Fedoniuk L, Khapitska O. Peculiarities of the chest’s size in female volleyball players of different constitutional types. Biomed Biosoc Anthropol. 2018;(33):47–52. DOI: [10.31393/bba33-2018-8](https://doi.org/10.31393/bba33-2018-8)
- [24] Karatieieva S, Slobodian O, Muzyka N, Slobodian K, Boichuk O. Dynamics comparison of the proximal thigh girth in student-athletes of Bukovyna. Bull Probl Biol Med. 2023;(168):367–73. DOI: [10.29254/2077-4214-2023-1-168-367-373](https://doi.org/10.29254/2077-4214-2023-1-168-367-373)
- [25] Pastuszak A, Buško K, Kalka E. Somatotype and body composition of volleyball players and untrained female students – reference group for comparison in sport. Anthropol Rev. 2016;79(4):461–70. DOI: [10.1515/anre-2016-0033](https://doi.org/10.1515/anre-2016-0033)
- [26] Fields JB, Metoyer CJ, Casey JC, Esco MR, Jagim AR, Jones MT. Comparison of body composition variables across a large sample of National Collegiate Athletic Association women athletes from 6 competitive sports. J Strength Cond Res. 2018;32(9):2452–57. DOI: [10.1519/JSC.0000000000002234](https://doi.org/10.1519/JSC.0000000000002234)
- [27] Sieroń A, Stachoń A, Pietraszewska J. Changes in body composition and motor fitness of young female volleyball players in an annual training cycle. Int J Environ Res Public Health. 2023;20(3):2473. DOI: [10.3390/ijerph2003247](https://doi.org/10.3390/ijerph2003247)

Антропометричні особливості кінцівок у волейболісток різних соматотипів

Лариса Сарафинюк

Доктор біологічних наук, професор
Вінницький національний медичний університет ім. М. І. Пирогова
21018, вул. Пирогова, 56, м. Вінниця, Україна
<https://orcid.org/0000-0001-8253-5997>

Інна Степаненко

Аспірант
Вінницький національний медичний університет ім. М. І. Пирогова
21018, вул. Пирогова, 56, м. Вінниця, Україна
<https://orcid.org/0000-0001-5589-4951>

Ольга Хапіцька

Кандидат медичних наук, доцент
Вінницький національний медичний університет ім. М. І. Пирогова
21018, вул. Пирогова, 56, м. Вінниця, Україна
<https://orcid.org/0000-0002-1333-5892>

Олена Лежньова

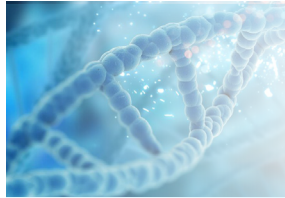
Кандидат медичних наук, доцент
Вінницький національний медичний університет ім. М. І. Пирогова
21018, вул. Пирогова, 56, м. Вінниця, Україна
<https://orcid.org/0000-0002-1393-3163>

Роман Власенко

Кандидат медичних наук, викладач
Вінницький національний технічний університет
21021, Хмельницьке шосе, 95, м. Вінниця, Україна
<https://orcid.org/0000-0001-7736-4564>

Анотація. Актуальність визначення антропометричних розмірів кінцівок, які визначають зовнішню будову тіла людини та мають тісні взаємозв'язки з техніко-тактичною діяльністю волейболістів, полягає у тому, що морфологічні ознаки можуть бути базисом для проведення кваліфікованого спортивного відбору. Мета даної роботи полягала у визначенні відмінностей величини антропометричних розмірів кінцівок між волейболістками та дівчатами, які не займалися спортом, в межах загальної групи і окремого конституціонального типу. Було проведено дослідження 108 волейболісток із середнім спортивним стажем $6,361 \pm 2,866$ років юнацького віку (середній вік – $18,05 \pm 1,39$ років). 130 практично здорових дівчат, які не займалися спортом, юнацького віку (середній вік – $17,91 \pm 1,49$ років) склали контрольну групу. Антропометрію проводили сертифікованим обладнанням за рекомендаціями П.П. Шапаренко, соматотипування – за методом Carter-Heath. Після визначення конституціональної приналежності волейболістки та неспортсменки були розділені на чотири групи: ектоморфного, мезоморфного, екто-мезоморфного та середнього проміжного соматотипів. Було встановлено, що у спортсменок усі обхватні розміри верхньої та нижньої кінцівок і ширина дистальних епіфізів стегна, гомілки, плеча та передпліччя достовірно більші, ніж у дівчат контрольної групи. Соматотипологічний підхід видозмінив характер попередніх результатів: у волейболісток всіх соматотипів порівняно з дівчатами контрольних груп відповідного типу конституції були статистично значуще більшими лише ширини епіфізів плеча та передпліччя; ширина дистального епіфізу гомілки була більшою лише у спортсменок середнього проміжного соматотипу, а ширина дистального епіфізу стегна була більшою у спортсменок екто-мезоморфного та середнього проміжного типів; більшість обхватних розмірів кінцівок були більшими лише у спортсменок ектоморфного та середнього проміжного соматотипів. Таким чином, волейболістки кожного конституціонального типу мають свої особливості будови кінцівок, які необхідно враховувати при створенні морфометричного профілю волейболісток і враховувати при спортивній орієнтації та прогнозуванні

Ключові слова: антропометрія; верхня та нижня кінцівки; конституціональні типи; волейбол



Peculiarities of professional burnout of nurses in war condition

Nataliia Smoliuk*

Postgraduate Student

I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0009-0004-9626-8155>

Arkadii Shulhai

Doctor of Medical Sciences, Professor

I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0002-2145-5851>

Abstract. Professional burnout among inpatient nurses who provide medical care to wounded military personnel is a significant problem for healthcare facilities, as it negatively affects the quality of care and requires further study to develop preventive measures at the individual and group levels to prevent it. The study aimed to conduct a comparative assessment of professional burnout among inpatient nurses providing medical care to military and civilian populations. A survey of 292 inpatient nurses was conducted. The level of professional burnout was determined according to the questionnaire by K. Maslach and S. Jackson. Correlation and regression analysis were used to determine the leading factors influencing the development of professional burnout in nurses. The study determined that the high level of emotional exhaustion in nurses who constantly worked with the military was 1.6 times ($p = 0.038$) higher than in nurses who were engaged in providing medical care to civilians and rarely worked with the military, depersonalisation was 1.8 times ($p = 0.007$), and the reduction of personal achievements was 1.9 times ($p = 0.022$). Using multivariate linear regression analysis, it was found that the presence of chronic diseases, age, length of service, the number of night shifts worked during the month, as well as the presence of children with a high level of statistical significance affect the development of professional burnout in nurses during the war. Conducting activities with nurses in the form of courses or lectures aimed at improving communication competencies helps to reduce the level of professional burnout

Keywords: healthcare professionals; health factors; medical care for the military; emotional exhaustion; regression analysis

★ INTRODUCTION

The level of professional burnout in nurses is more pronounced compared to other healthcare professions [1]. This is due to the heavy workload of nurses in the performance of their professional duties, and their high responsibility not only for the health of patients but also for their lives. N. Terenda *et al.* [2] emphasise that nurses often face extreme conditions at their workplaces that require immediate decision-making, patients in terminal conditions, and conditions of severe psycho-emotional stress, which leads to emotional exhaustion and depersonalisation. However, researchers do not distinguish separately the relationship between socio-demographic and professional factors and the level of burnout.

L. Buckley *et al.* [3] point out that by performing a large amount of work related to the medical and diagnostic process, nurses experience serious physical and psychological stress, which can lead to exhaustion, and then to a decrease in productivity, errors in clinical conditions and a decrease in care in the treatment of patients, which are signs of professional burnout.

M.K. Shah *et al.* [4] proved through numerous questionnaires that nurses working in inpatient departments have a higher chance of developing burnout than nurses working in outpatient departments. The authors also note the impact of the duration of work hours during the week on the development of professional burnout of nurses.

Suggested Citation:

Smoliuk N, Shulhai A. Peculiarities of professional burnout of nurses in war conditions. Bull Med Biol Res. 2024;6(1):64–72. DOI: 10.61751/bmbr/1.2024.64

*Corresponding author



Currently, there is a need to identify the leading factors that determine the development of professional burnout of nurses in different departments to develop measures aimed at reducing and preventing burnout. The stressful nature of nurses' work often leads to the development of the highest levels of burnout and, in some cases, disability. A. Larysz *et al.* [5] stated that the level of emotional exhaustion of nurses correlates with the severity of depression symptoms. Furthermore, A.D. Guastello *et al.* [6] demonstrated that among all the predictors of increased burnout, symptoms of depression and anxiety are identified, which complement the influence of other factors. However, the authors conducted a general comparative assessment and did not consider socio-demographic, and professional factors, as well as the conditions of social life and crisis events. Crisis events have a significant impact on the mental health of nurses, acting as additional stressors for the development of professional burnout. War is considered one of the most pronounced crises [7].

To date, few studies highlight the impact of the Russian-Ukrainian war, as well as the specifics of medical care and military care, on the state of professional burnout of nurses. Only a few reports indicate that depression, combined with emotional exhaustion, is on the rise among Ukrainians in both frontline and rear regions [8]. In this regard, to ensure the quality performance of professional duties by nurses, it is advisable to establish the level of professional burnout of nurses working in war conditions in hospitals with military and civilian populations.

The study aimed to identify the main socio-demographic and professional factors that influence the development of professional burnout among inpatient nurses who provide medical care to the military and civilian populations. The objectives of the study were to conduct a comparative assessment of the level of professional burnout depending on socio-demographic and professional characteristics, to establish correlations between the characteristics of professional burnout and these factors, and to identify the leading factors that influence the level of professional burnout.

✦ MATERIALS AND METHODS

This study was cross-sectional and included the study of professional burnout of nurses in the departments of

cluster and supercluster healthcare facilities that provide medical care to the military and civilian population of Ternopil, Ivano-Frankivsk and Zaporizhzhia regions and its relationship with socio-demographic, professional and personal factors. The survey was conducted over three months (from 30.10.2023 to 01.02.2024) by filling out a printed questionnaire by nurses of the therapeutic and surgical departments. Based on the results of the survey, a database table was formed and subjected to statistical processing.

The reliability and validity of the instruments used to measure professional burnout were assessed by calculating Cronbach's alpha reliability coefficient. Questionnaires with a Cronbach's alpha greater than 0.75 are considered reliable. The questionnaire used was characterised by a high level of reliability (Cronbach's alpha was $\alpha=0.95$) according to a preliminary test [9]. The criterion for inclusion in the study group was the presence of informed consent from the participants.

The statistical population included 292 inpatient nurses who answered the questionnaire, which included questions of a socio-demographic, professional and organisational nature, as well as 22 questions of the questionnaire by K. Maslach and S. Jackson [9], which is the most adapted to characterise the professional burnout of social workers. Questions of a socio-demographic, professional and organisational nature were added: age; gender; length of service; marital status; presence of children; number of children; position title; departments where nurses work; work of a nurse in a department with military (civilian population); work with wounded (sick) servicemen (permanently, periodically, not working); number of night shifts per month; presence of chronic diseases; completion of courses (lectures) on the peculiarities of communication with the military; completion of advanced training courses in the last 3 years. 22 items grouped into 3 subscales: emotional exhaustion (EE, nine items), depersonalisation (DP, five items) and reduction of personal achievement (PA, eight items). Each item was answered on a 7-point Likert scale ranging from: "never" – 0 points; "several times a year or less" – 1 point; "once a month" – 2 points; "several times a month" – 3 points; "once a week" – 4 points; "several times a week" – 5 points; "daily" – 6 points. The level of burnout for each subscale was set according to the sum of the scores obtained (Table 1).

Table 1. Levels of burnout following K. Maslach and S. Jackson

Subscale	Low level (number of points)	Average level (number of points)	High level (number of points)
Emotional exhaustion	0-16	17-26	27 and more
Depersonalisation	0-6	7-12	13 and more
Reduction of personal achievements	39 and more	38-32	0-31

Source: Source: [9]

Statistical analysis of the results was carried out on a personal computer using SPSS version 21 software. Descriptive statistics methods were used to determine the prevalence of the components of professional burnout. Frequency characteristics of the studied traits were described as absolute value (n) and percentage (%). A comparison of frequency indices between groups was performed using Pearson's chi-square (χ^2) test. Comparison of quantitative indicators of the observation groups was carried out by determining the Student's t-test for

independent samples, and in the case of three or more groups, a one-factor analysis of variance with Bonferoni correction was used. Differences between groups were considered significant at $p < 0.05$.

Pearson's correlation analysis was conducted to establish the relationship between the level of burnout and socio-demographic, organisational and professional factors. Multiple regression analysis was used to determine the leading factors that influence the development of professional burnout in nurses.

The study was conducted following the principles of good clinical practice and the World Medical Association's Declaration of Helsinki on the Ethical Principles for Scientific Medical Research Involving Human Subjects [10]. All survey participants were informed about how their anonymity is ensured, they know why the survey is being conducted, how the data they provide will be used, and the risks involved. The Bioethics Commission of the Ternopil Gorbachevsky National Medical University of the Ministry of Health of Ukraine certified the compliance of the research with moral and ethical standards (Protocol No. 27 of 29 January 2024).

RESULTS

The study surveyed 292 nurses working in various departments of cluster and supercluster healthcare facilities providing medical care to the military and civilian population.

Among the respondents, there were 283 women (96.92%) and 9 men (3.08%) (Table 2). The majority (41.43%) of them belonged to the age group under 35. According to marital status, 173 (59.24%) of the respondents were married, and 205 (70.21%) had 1 to 3 children. All the respondents worked in inpatient departments as nurses, with most of them on duty 215 people (73.63%), i.e. they provided direct nursing care to patients. Most of the survey participants were nurses with more than 20 years of work experience – 116 (39.73%). Regarding the patients with whom the study participants worked, 117 (40.06%) were engaged in providing medical care to the military regularly, and 65 (22.26%) worked only with the civilian population. Among the participants, 210 (71.92%) had attended lectures or courses on communication with wounded or sick soldiers, and 183 (62.67%) had taken some kind of advanced training course in the last 3 years.

Table 2. Socio-demographic and professional characteristics of nurses (n = 292)

Variable	Variable categories	n (%)	Significance of differences in groups, p
Gender	Male	9 (3.08)	< 0.001
	Female	283 (96.92)	
Age (years)	< 35	121 (41.43)	< 0.001
	35-49	101 (34.59)	
	≥ 50	70 (23.97)	
Marital status	Married (married)	173 (59.24)	< 0.001
	Single (unmarried)	81 (27.74)	
	Divorced (divorced)	38 (13.01)	
Presence of children	Yes	205 (70.21)	< 0.001
	No	87 (29.79)	
Position	Nurse on duty	215 (73.63)	< 0.001
	Manipulative nurse	37 (12.67)	
	Dressing nurse	11 (3.77)	
	Operating room nurse	29 (9.93)	
Service term	> 5	52 (17.80)	< 0.001
	5-10	62 (21.23)	
	11-20	62 (21.23)	
	20 <	116 (39.73)	
Work with wounded (sick) servicemen	Always	117 (40.06)	< 0.001
	Periodically	96 (32.87)	
	Rarely	14 (4.79)	
	Only with civilians	65 (22.26)	
Attendance of courses (lectures) on the specifics of communication with the military	Yes	210 (71.92)	< 0.001
	No	82 (28.08)	
Attendance of advanced training courses in the last 3 years	Yes	183 (62.67)	< 0.001
	No	109 (37.33)	

Notes: p-values are obtained using the chi-square test for categorical variables; n, absolute number of observations

Source: compiled by the authors

A comparative assessment of the average indicators of the components of professional burnout depending on various socio-demographic and professional characteristics of the group of surveyed nurses was carried out (Table 3). The study determined that females who work as nurses, compared to males, have a 24.1% ($p=0.213$) higher level of EE, 36.3% ($p=0.190$) higher level of DP and 9.2% ($p=0.164$) lower level of RA. As such, the level of EE among nurses under 35 years of age is 30.1% higher compared to nurses aged 50 and older, and 13.2% higher compared to the age

group 35-49 years. In general, a significant difference in EE ($p=0.017$) and RA ($p=0.035$) was found between the age groups. The average values of DP in the group of respondents under 35 and in the group of 35-49 years old are of medium DP level, and in people aged 50 and older – low DP level, although there was no significant intergroup difference in DP levels by age ($p=0.238$). Marital status also influenced the level of manifestation of EE, DP, and RA. Married nurses had the highest EE score, which corresponded to the average level of burnout, and unmarried nurses had

the lowest ($p=0.032$). The highest level of DP was found in unmarried nurses, which, like divorced nurses, was related to the average level of DP by its numerical values. The DP rate for married people was low. Among the characteristics of marital status, RA was most pronounced in unmarried

nurses, whose values, like those of divorced nurses, were related to the average level of RA. In married people, RA was low ($p=0.046$). Nurses who had children had 11.4% higher EE ($p=0.098$), lower DP ($p=0.419$) and significantly lower RA ($p=0.046$).

Table 3. Comparative assessment of the average indicators of emotional exhaustion, depersonalisation and reduction of personal achievements depending on the sociodemographic and professional characteristics of nurses ($n=292$)

Variable	Variable categories	Emotional exhaustion		Depersonalisation		Reduction of personal achievements	
		M ± SD	Level of confidence, p	M ± SD	Level of confidence, p	M ± SD	Level of confidence, p
Gender	Male	14.66 ± 9.02	0.213	5.56 ± 4.36	0.190	36.33 ± 8.29	0.164
	Female	18.20 ± 12.37		7.58 ± 5.29		39.67 ± 7.46	
Age (years)	< 35	18.13 ± 13.43	0.017	7.19 ± 4.75	0.238	36.60 ± 8.13	0.035
	35-49	16.01 ± 12.82		6.85 ± 4.93		38.24 ± 7.03	
	≥ 50	13.94 ± 11.37		5.50 ± 4.68		39.08 ± 6.78	
Marital status	Married (married)	18.37 ± 11.04	0.032	5.89 ± 5.02	0.263	39.07 ± 7.20	0.046
	Single (unmarried)	14.65 ± 13.24		7.63 ± 5.90		35.65 ± 8.42	
	Divorced (divorced)	16.32 ± 13.32		6.70 ± 5.22		38.83 ± 6.41	
Presence of children	Yes	17.82 ± 13.25	0.098	6.88 ± 5.17	0.419	39.29 ± 7.03	0.046
	No	15.96 ± 13.49		7.02 ± 5.54		37.48 ± 8.42	
Position	Nurse on duty	14.05 ± 12.65	0.012	6.49 ± 4.91	0.001	38.28 ± 7.90	0.278
	Manipulative nurse	22.78 ± 16.26		9.35 ± 6.74		38.73 ± 6.65	
	Dressing nurse	17.39 ± 13.04		3.63 ± 3.72		39.27 ± 6.13	
	Operating room nurse	16.35 ± 12.74		5.64 ± 4.96		40.92 ± 5.36	
Service term	> 5	18.68 ± 14.71	0.027	7.82 ± 6.29	0.122	37.73 ± 8.61	0.267
	5-10	16.09 ± 12.56		6.06 ± 5.37		37.83 ± 7.97	
	11-20	15.58 ± 12.86		5.79 ± 4.68		39.22 ± 7.06	
	20 <	13.91 ± 13.36		5.52 ± 5.06		39.70 ± 6.92	
Work with wounded (sick) servicemen	Always	18.91 ± 14.17	0.035	7.56 ± 5.41	0.214	35.34 ± 6.37	0.001
	Periodically	14.21 ± 11.58		6.57 ± 4.17		38.97 ± 6.77	
	Rarely	11.07 ± 12.82		4.35 ± 4.19		39.76 ± 12.71	
	Only with civilians	16.12 ± 14.17		6.54 ± 6.61		39.43 ± 8.22	
Attendance of courses (lectures) on the specifics of communication with the military	Yes	15.18 ± 13.06	0.041	5.71 ± 5.24	0.275	39.29 ± 7.34	0.050
	No	17.92 ± 13.88		7.48 ± 5.39		36.38 ± 7.76	
Attendance of advanced training courses in the last 3 years	Yes	15.35 ± 13.41	0.101	5.86 ± 5.74	0.316	39.91 ± 7.62	0.670
	No	17.68 ± 13.20		7.97 ± 5.38		38.52 ± 7.12	

Notes: p-values for comparison of two groups were obtained by determining the Student's t-test; p-values for comparison of three or more groups were obtained by using one-factor analysis of variance with Bonferroni correction; n, absolute number of observation units; M ± SD, mean value and its standard deviation

Source: compiled by the authors

Significant differences in professional burnout among nurses who worked in different positions and performed different tasks were noted. The highest level of EE was observed in manipulation nurses, lower in dressing and operating room nurses, and the lowest in those on duty at the nursing post ($p=0.012$). The level of DP was also the highest in manipulation nurses and the lowest in dressing nurses ($p=0.001$). Moreover, the average DP values of manipulation and post nurses were of medium

burnout level, and operating and dressing nurses had a low level. There was no significant difference in the RA of nurses depending on their positions, but it was determined that the average value of RA of post and manipulation nurses belongs to the average level of burnout and operating and dressing nurses to the low level of burnout. The results of the questionnaire revealed that EE, DP and RA have the greatest manifestations in nurses with less than 5 years of experience. The level of EE among nurses

with less than 5 years of work experience is 34.3% higher than the level of EE among nurses with more than 20 years of work experience.

The results of the study on the state of professional burnout of nurses who work with the military permanently, periodically or only with the civilian population are important. As determined, the highest values of EE, DP, and RA were determined in nurses who constantly work with wounded or sick military personnel. The numerical values of EE in nurses who constantly work with wounded or sick military personnel are 70.8% higher than those of nurses who rarely work with this patient population, DP by 73.7%, and RA by 12.5%.

The impact of professional development activities, as well as taking a course or listening to lectures on the peculiarities of communication with the military on the state of EE, DP, and RA was analysed. Nurses who attended a course on the peculiarities of communication with the military had significantly lower EE ($p = 0.041$) and RA ($p = 0.050$). Professional development in the form of advanced training courses over the past 3 years has had a significant impact on the components of professional burnout.

A comparative assessment of the prevalence of professional burnout among nurses engaged in regular medical care for the military and those who provide medical care to the military rarely or only to the civilian population has revealed that it has significant differences in terms of severity (Table 4). The high level of EE in nurses who constantly worked with the military was 1.6 times ($p = 0.038$) higher than in nurses who were engaged in providing medical care to civilians and rarely worked with the military, DP by 1.8 times ($p = 0.007$), and RA by 1.9 times ($p = 0.022$). The prevalence of low EE in nurses who constantly worked with the military compared to nurses who provided medical care only to the civilian population was 2.2 times lower ($p = 0.003$), DP 2.2 times lower ($p = 0.005$), and RA 1.7 times lower ($p = 0.021$). There was no significant difference in the prevalence of medium level of professional burnout among these categories of nurses. However, the frequency of medium-level manifestations in nurses who worked with military EE was 1.1 times higher and DP 1.2 times higher. Thus, nurses who worked in the military had high levels of emotional exhaustion, depersonalisation and reduction of personal achievements.

Table 4. Burnout rates of inpatient nurses in healthcare facilities providing medical care to military and civilian populations, n (%)

Subscale burnout	Working with military personnel	Low level, p (%)	Average level, p (%)	High level, p (%)
Emotional exhaustion	Constantly, n = 117	18 (15.4)	51 (43.5)	48 (41.1)
	Rarely or only work with civilians, n = 79	27 (34.3)	31 (39.2)	21 (26.5)
	Level of confidence, <i>p</i>	0.003	0.545	0.038
Depersonalisation	Constantly, n = 117	16 (13.7)	56 (47.8)	45 (38.5)
	Rarely or only work with civilians, n = 79	24 (30.4)	39 (40.3)	16 (20.3)
	Level of confidence, <i>p</i>	0.005	0.837	0.007
Reduction of personal achievements	Constantly, n = 117	24 (20.5)	56 (47.9)	37 (31.6)
	Rarely or only work with civilians, n = 79	28 (35.4)	38 (48.1)	13 (16.5)
	Level of confidence, <i>p</i>	0.021	0.911	0.022

Notes: p-value for comparison of two groups was obtained by determining the Student's t-test; n-absolute number of observation units

Source: compiled by the authors

The correlation analysis revealed the main categorical and continuous variables of socio-demographic, professional, organisational and personal characteristics that have interrelations with the development of professional burnout in nurses during martial law (Table 5). Emotional exhaustion is characterised by significant correlations with age, nurse's position, length of service, the contingent of patients in whose care the nurse is involved, the number of night shifts for one month, the number of children, the length of time the nurse has worked in the military unit,

the presence of chronic diseases, and courses (lectures) on the specifics of communication with the military. Depersonalisation is determined by reliable correlations with length of service, number of night shifts for one month, and the presence of chronic diseases. The reduction of personal achievements is characterised by significant correlations with age, nurse position, length of service, presence of children, length of service in the military unit, and completion of courses (lectures) on the specifics of communication with the military.

Table 5. Correlations between indicators of professional burnout and socio-demographic, organisational and professional characteristics of nurses

Characteristics		Emotional exhaustion	Depersonalisation	Reduction of personal achievements
Age	The correlation coefficient, <i>r</i>	-,151	-,071	,135
	<i>P</i>	,005	,114	,011
Gender	Correlation coefficient, <i>r</i>	,020	,013	,082
	<i>P</i>	,366	,415	,082
Position	Correlation coefficient, <i>r</i>	,157	,036	,111
	<i>P</i>	,006	,271	,030

Table 5. Continued

Characteristics		Emotional exhaustion	Depersonalisation	Reduction of personal achievements
Service term	Correlation coefficient, <i>r</i>	-,147	-,103	,099
	<i>P</i>	,008	,010	,046
The contingent of patients	The correlation coefficient, <i>r</i>	-,129	-,070	-,062
	<i>P</i>	,014	,116	,147
Number of night shifts per month	The correlation coefficient, <i>r</i>	,181	,183	-,061
	<i>P</i>	,001	,001	,149
Marital status	The correlation coefficient, <i>r</i>	,012	,003	-,009
	<i>P</i>	,419	,483	,438
Presence of children	The correlation coefficient, <i>r</i>	-,039	-,012	,110
	<i>P</i>	,253	,421	,030
Number of children	The correlation coefficient, <i>r</i>	,122	,036	,041
	<i>P</i>	,041	,303	,282
Duration of work in the branch with military personnel	The correlation coefficient, <i>r</i>	,123	,023	,215
	<i>P</i>	,015	,347	,000
Presence of chronic diseases	The correlation coefficient, <i>r</i>	,293	,244	,049
	<i>P</i>	,000	,000	,204
Attendance of courses (lectures) on the peculiarities of communication with the military	The correlation coefficient, <i>r</i>	,112	,065	-,114
	<i>P</i>	,038	,134	,026
Attendance of advanced training courses in the last 3 years	The correlation coefficient, <i>r</i>	,030	,006	-,025
	<i>P</i>	,304	,456	,335

Notes: *r*-value of the correlation coefficient; *p*-level of reliability of correlations between indicators

Source: compiled by the authors

Multivariate linear regression analysis using a generalised indicator of nurses' burnout as a dependent variable (Table 6) the main characteristics that affect the level of

burnout are identified. The regression model covers most of the factors that influence the level of professional burnout ($R^2 = 0.767$).

Table 6. Results of multiple regression analysis of medical students' performance with indicators of trauma, depression, anxiety and stress

Predictor	Non-standard coefficients		Standard coefficients, β	p-value
	B	Standard error, B		
Constant	35.392	7.076		0.000
Presence of chronic diseases	-11.883	1.794	-,440	0.000
Presence of children	7.844	3.526	,238	0.027
Age	-3.880	1.761	-,216	0.029
Number of night shifts per month	-,721	,256	-,191	0.005
Service term	-2.925	1.725	-,187	0.042

Notes: B – unstandardised regression coefficient; β – standardised regression coefficient; $R=0.876$; $R^2=0.767$; $F=6.959$

Source: compiled by the authors

The obtained model showed that the presence of chronic diseases, age, length of service, the number of night shifts worked during the month, as well as the presence of children have a high level of reliability in influencing the development of professional burnout among nurses during the war. Thus, when planning and implementing measures to prevent professional burnout among nurses during war-time who provide medical care to the military and civilian population, the intervention groups should primarily include young nurses under 35 years of age, with up to 5 years of work experience, children, chronic diseases, and those who often work night shifts. Among the measures to prevent professional burnout, it is imperative to conduct

classes on the specifics of communication with wounded soldiers undergoing treatment in hospital departments.

DISCUSSION

The study found that nurses who are constantly involved in the provision of medical care to the military were diagnosed with high and 43.5% of cases of EE, 38.5% of cases of high and 47.8% of cases of DP, 31.6% of cases of high and 47.9% of cases of RA. Among inpatient nurses who rarely work with military personnel or work only with civilians, a high level of EE was found in 26.5%, DP in 20.3%, and RA in 16.5%.

Depending on the complexity and level of healthcare provision in different countries, researchers note different

levels of professional burnout among nurses. For instance, in private clinics in Ethiopia, where 56.8% and 56.3% had high levels of EE and DP, respectively, and 56.3% had low levels of PA. The prevalence of EE, DP, and RA among nurses in palliative care facilities was 19.5%, 9.3%, and 8.2%, respectively [11]. Nurses who worked during the COVID-19 pandemic had higher levels of EE but lower DP and RA compared to psychiatric nurses, primary care nurses, oncology nurses, paediatric nurses, and emergency nurses [12]. S. Yang *et al.* [13] determined that the denotative indicator of the level of professional burnout is the EE subscale. The results of the study by G. Hur *et al.* [12] point out the correlation between the level of professional burnout of nurses and the complexity of the work performed in the department and job responsibilities.

The comparative analysis revealed that the highest level of EE and DP among nurses of healthcare facilities providing medical care to the military and civilian population was determined by nurses responsible for performing medical manipulations, and the highest level of RA in post and manipulation nurses. The level of professional burnout depends on the departments in which nurses work. Thus, according to the research of M. Al Maqbali *et al.* [14], conducted in the United States, 61% of intensive care unit workers experienced EE, 44% had symptoms of DP, and 50% experienced RA. Researchers also link the development of professional burnout to various types of stress. This is especially relevant during the war, when most employees, like the entire population of Ukraine, are under constant stress. Researchers [15] believe that 58.43% of respondents had a high level of stress in the development of professional burnout among intensive care unit nurses.

An important component of the study of professional burnout is the establishment of relationships between the level of professional burnout or its components and socio-demographic, professional or organisational factors. The correlation analysis revealed no significant relationship between gender and the level of professional burnout. The same data was obtained by other researchers in Portugal, Brazil, the USA and Greece [16].

Professional burnout in nurses has a close relationship with age. The correlation analysis of the conducted studies revealed that the age of nurses has a significant inverse correlation with EE ($p=0.005$) and a direct correlation with RA ($p=0.011$). This may be since young people are more professionally active, overusing their energy and commitment.

Studies have shown that professional burnout depends on the length of service of employees [17]. According to the data obtained, EE and DP have an inverse significant correlation with seniority, and RA has a significant direct correlation. This is supported by other researchers who explain the higher incidence of burnout among younger workers by the fact that they are more likely to take on more professional responsibilities, focus on maintaining high-quality services and seek solutions to nursing problems without having the relevant experience. On the other hand, it is believed that the longer the length of service in the profession, the lower the level of impartiality in professional relationships [4].

Many researchers have shown that nurses with families have a significantly higher tendency to experience professional burnout than single nurses, which the authors

explain by the additional burden of household responsibilities and emotional involvement in their family's affairs. These findings are also confirmed by a meta-analysis of 78 studies on the impact of socio-demographic factors on the occurrence of professional burnout syndrome [18].

The research also confirms a higher level of EE in married nurses ($p=0.032$) compared to unmarried nurses. However, no significant correlations between the marital status of nurses and the level of professional burnout were found. However, there are significant correlations between the level of RA and the presence of children in nurses ($p=0.030$), and it was found that the number of children in nurses is characterised by a significant correlation with the level of EE ($p=0.041$). Many literature sources indicate the influence of psychological factors on nurses' burnout [12, 19], because nurses are more likely to face psychological problems than other healthcare workers, and this situation is more difficult for them [20, 21]. The analysis of the studies showed that insomnia and perception of one's health as poor were positively correlated with burnout, while psychological resilience was negatively correlated with EE.

According to the data, both emotional exhaustion and depersonalisation have a significant direct correlation with the frequency of night shifts during the month. Among the causes of professional burnout associated with night work, researchers point out that working the night shift disrupts a person's circadian cycle, rest and sleep. Those who work night shifts must sleep during the day when there is no way to get a deep and quality sleep. This affects the physiological balance of a person [22]. Among the existing studies, insufficient attention has been devoted to the relationship between professional burnout and nurses' chronic diseases and health status in general. The correlation analysis confirmed direct correlations of EE ($p=0.000$) and DP ($p=0.000$) with existing chronic diseases with a high level of confidence. As a result of the conducted research, a multiple regression analysis model was obtained, according to which it was determined that the main group of factors influencing the development of professional burnout includes age, length of service, presence of children, number of night shifts worked during the month, and the presence of chronic diseases in nurses. In this regard, these factors should be addressed when planning and developing measures to prevent professional burnout of nurses.

✦ CONCLUSIONS

Nurses who are constantly involved in providing medical care to the military in inpatient departments have a high level of emotional exhaustion at 41.1%, depersonalisation at 38.5%, and a reduction in personal achievements at 31.6%, which is significantly higher than the data on the components of burnout of nurses who are involved in providing medical care only to the civilian population. The professional burnout of inpatient nurses who are constantly engaged in the provision of medical care and work in healthcare facilities that provide medical care to the military and civilian population is associated with many socio-demographic, professional and organisational factors. Among these factors, nurses' professional burnout is significantly correlated with nurses' age, length of service, duration of work with wounded (sick) military personnel,

work experience, presence of chronic diseases, and married nurses with children. According to the results of multiple regression analysis, it was found that the main factors that have a decisive influence on the development of professional burnout in nurses during the war include age, length of service, presence of children, the number of night shifts worked during the month, and the presence of chronic diseases in nurses. These factors determine the level of professional burnout in 76.7% of cases. Providing additional courses for nurses on the specifics of communication with wounded soldiers helps to reduce the level of emotional exhaustion and reduce personal achievements, which reduces the impact of various factors on the development of professional burnout. The results of the research can be used to develop methods for preventing professional burnout in

nurses involved in providing medical care to the military, as well as to develop a strategy for managing a healthcare facility to improve the provision of healthcare services. Prospects for further research in this area are to develop and scientifically substantiate effective intervention measures aimed at reducing and preventing professional burnout among nurses providing medical care to the military and civilian population during the war.

✦ ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the university administration for the opportunity to conduct the study.

✦ CONFLICT OF INTEREST

The authors declare no conflict of interest.

✦ REFERENCES

- [1] Galanis P, Vraika I, Fragkou D, Bilali A, Kaitelidou D. Nurses' burnout and associated risk factors during the COVID-19 pandemic: A systematic review and meta-analysis. *J Adv Nurs*. 2021;77(8):3286–2. DOI: [10.1111/jan.14839](https://doi.org/10.1111/jan.14839)
- [2] Terenda N, Pavliv T, Terenda O. Occupational burning is one of the unsolved problems of the healthcare system. *Bull Soc Hyg Health Prot Organ Ukr*. 2021;(2):29–33. DOI: [10.11603/1681-2786.2021.2.12377](https://doi.org/10.11603/1681-2786.2021.2.12377)
- [3] Buckley L, Berta W, Cleverley K, Medeiros C, Widger K. What is known about paediatric nurse burnout: A scoping review. *Hum Resour Health*. 2020;18(1):9. DOI: [10.1186/s12960-020-0451-8](https://doi.org/10.1186/s12960-020-0451-8)
- [4] Shah MK, Gandrakota N, Cimiotti JP, Ghose N, Moore M, Ali MK. Prevalence of and factors associated with nurse burnout in the US. *JAMA Netw Open*. 2021;4(2). DOI: [10.1001/jamanetworkopen.2020.36469](https://doi.org/10.1001/jamanetworkopen.2020.36469)
- [5] Larysz A, Prokopowicz A, Zakliczyński M, Uchmanowicz I. Occurrence of professional burnout and severity of depressive symptoms among cardiac nurses: A cross-sectional study. *Int J Environ Res Public Health*. 2021;18(22):12038. DOI: [10.3390/ijerph182212038](https://doi.org/10.3390/ijerph182212038)
- [6] Guastello AD, Brunson JC, Sambuco N, Dale LP, Tracy NA, Allen BR, Mathews CA. Predictors of professional burnout and fulfilment in a longitudinal analysis on nurses and healthcare workers in the COVID-19 pandemic. *J Clin Nurs*. 2024;33(1):288–3. DOI: [10.1111/jocn.16463](https://doi.org/10.1111/jocn.16463)
- [7] Tsybuliak N, Suchikova Y, Shevchenko L, Popova A, Kovachev S, Hurenko O. Burnout dynamic among Ukrainian academic staff during the war. *Sci Rep*. 2023;13:17975. DOI: [10.1038/s41598-023-45229-6](https://doi.org/10.1038/s41598-023-45229-6)
- [8] Kurapov A, Danyliuk I, Loboda A, Kalaitzaki A, Kowatsch T, Klimash T, Predko V. Six months into the war: A first-wave study of stress, anxiety, and depression among in Ukraine. *Front Psychiatry*. 2023;14:1190465. DOI: [10.3389/fpsy.2023.1190465](https://doi.org/10.3389/fpsy.2023.1190465)
- [9] Maslach C, Jackson SE. The measurement of experienced burnout. *J Organ Behav*. 1981;2(2):99–13. DOI: [10.1002/job.4030020205](https://doi.org/10.1002/job.4030020205)
- [10] The World Medical Association. Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects [Internet]. cited 2024 Jan 4]. Available from: <https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/>
- [11] Parola V, Coelho A, Cardoso D, Sandgren A, Apóstolo J. Prevalence of burnout in health professionals working in palliative care: A systematic review. *JBISRI-2016-003309*. 2017;15(7):1905–33. DOI: [10.11124/JBISRI-2016-003309](https://doi.org/10.11124/JBISRI-2016-003309)
- [12] Hur G, Cinar N, Karakaya O, Suzan O. Impact of COVID-19 pandemic on nurses' burnout and related factors: A rapid systematic review. *Appl Nurs Res*. 2022;41:248–63. DOI: [10.1016/j.apnu.2022.09.002](https://doi.org/10.1016/j.apnu.2022.09.002)
- [13] Yang C, Wang X, Zhang X, Liu W, Wang C. Burnout and associative emotional status and coping style of healthcare workers in COVID-19 epidemic control: A cross-sectional study. *Front Public Health*. 2023;11:1079383. DOI: [10.3389/fpubh.2023.1079383](https://doi.org/10.3389/fpubh.2023.1079383)
- [14] Al Maqbali M, Al Sinani M, Al-Lenjawi B. Prevalence of stress, depression, anxiety and sleep disturbance among nurses during the COVID-19 pandemic: A systematic review and meta-analysis. *J Psychosom Res*. 2021;141:110343. DOI: [10.1016/j.jpsychores.2020.110343](https://doi.org/10.1016/j.jpsychores.2020.110343)
- [15] Michalak M, Brzozowska J, Kazimierska-Zajac M. Level of professional burnout and sense of coherence among nurses working in the department of anesthesiology and intensive care. *J Neurological Neurosurgical Nursing*. 2022;11(1):8–13. DOI: [10.15225/PNN.2022.11.1.2](https://doi.org/10.15225/PNN.2022.11.1.2)
- [16] Fradelos E, Tzitzikos G, Giannouli V, Argyrou P, Vassilopoulou C, Theofilou P. Assessment of burn-out and quality of life in nursing professionals: The contribution of perceived social support. *Health Psychol Res*. 2014;2(1). DOI: [10.4081/hpr.2014.984](https://doi.org/10.4081/hpr.2014.984)
- [17] Diehl E, Rieger S, Letzel S, Schablon A, Nienhaus A, Escobar Pinzon LC, Dietz P. The relationship between workload and burnout among nurses: The buffering role of personal, social and organisational resources. *PLoS One*. 2021;16(1). DOI: [10.1371/journal.pone.0245798](https://doi.org/10.1371/journal.pone.0245798)

- [18] Cañadas-De la Fuente GA, Ortega E, Ramirez-Baena L, De la Fuente-Solana EI, Vargas C, Gómez-Urquiza JL. Gender, marital status, and children as risk factors for burnout in nurses: A meta-analytic study. *Int J Environ Res Public Health*. 2018;15(10):2102. DOI: [10.3390/ijerph15102102](https://doi.org/10.3390/ijerph15102102)
- [19] Tang L, Yu X, Wu Y, Zhao N, Liang R, Gao X, et al. Burnout, depression, anxiety and insomnia among medical staff during the COVID-19 epidemic in Shanghai. *Front Public Health*. 2022;10:1019635. DOI: [10.3389/fpubh.2022.1019635](https://doi.org/10.3389/fpubh.2022.1019635)
- [20] Patel RS, Bachu R, Adikey A, Malik M, Shah M. Factors related to physician burnout and its consequences: A review. *Behav Sci*. 2018;8(11):98. DOI: [10.3390/bs8110098](https://doi.org/10.3390/bs8110098)
- [21] Jarosz K, Zborowska A, Młynarska A. Rationing care, job satisfaction, fatigue and the level of professional burnout of nurses in urology departments. *Int J Environ Res Public Health*. 2022;19(14):8625. DOI: [10.3390/ijerph19148625](https://doi.org/10.3390/ijerph19148625)
- [22] Kissel KA, Filipek C, Jenkins J. Impact of the COVID-19 Pandemic on nurses working in intensive care Units: A scoping review. *Crit Care Nurse*. 2023;43(2):55–63. DOI: [10.4037/ccn2023196](https://doi.org/10.4037/ccn2023196)

Особливості професійного вигорання медичних сестер стаціонарів в умовах війни

Наталія Смолюк

Аспірант

Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України

46001, майдан Волі, 1, м. Тернопіль, Україна

<https://orcid.org/0009-0004-9626-8155>

Аркадій Шульгай

Доктор медичних наук, професор

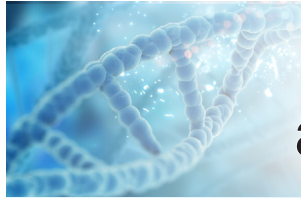
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України

46001, майдан Волі, 1, м. Тернопіль, Україна

<https://orcid.org/0000-0002-2145-5851>

Анотація. Професійне вигорання серед медсестер стаціонарів, які надають медичну допомогу пораненим військовим є значною проблемою для закладів охорони здоров'я, оскільки негативно впливає на якість надання медичної допомоги та потребує додаткового вивчення для розробки профілактичних заходів на особистісному та груповому рівні щодо його попередження. Метою дослідження було провести порівняльну оцінку професійного вигорання медичних сестер стаціонарів, які надають медичну допомогу військовим та цивільному населенню. Проведено анкетування 292 медичних сестер відділень стаціонарів. Рівень професійного вигорання встановлювали згідно опитувальника К. Маслач і С. Джексона. З метою визначення провідних чинників, які впливають на розвиток професійного вигорання у медсестер, застосовували кореляційно-регресійний аналіз. Встановлено, що високий рівень емоційного виснаження у медсестер, які постійно працювали з військовими у 1,6 разу ($p = 0,038$) переважав такий у медсестер, які були зайняті наданням медичної допомоги цивільним та рідко працювали з військовими, деперсоналізації в 1,8 разу ($p = 0,007$), а редукції особистих досягнень в 1,9 разу ($p = 0,022$). Застосуванням багатофакторного лінійного регресійного аналізу встановлено, що наявність хронічних захворювань, вік, стаж роботи, кількість відпрацьованих нічних змін протягом місяця, а також наявність дітей з високим рівнем статистичної значущості впливають на розвиток у медичних сестер в період війни професійного вигорання. Проведення з медичними сестрами заходів у формі курсів або лекцій, направлених на покращення комунікативних компетентностей сприяє зниженню рівня професійного вигорання

Ключові слова: медичні працівники; чинники здоров'я; медична допомога військовим; емоційне виснаження; регресійний аналіз



Morphological changes in structural components of human heart valves associated with chronic haemodynamic trauma

Larysa Fedoniuk*

Doctor of Medical Sciences, Professor
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0003-4910-6888>

Olena Rudenko

PhD in Medical Sciences, Senior Research Fellow
M. M. Amosov National Institute of Cardiovascular Surgery
02000, 6 Mykoly Amosova Str., Kyiv, Ukraine
<https://orcid.org/0000-0003-3640-566X>

Olena Ruzhytska

PhD in Biological Sciences, Assistant Professor
I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine
46001, 1 Maidan Voli, Ternopil, Ukraine
<https://orcid.org/0000-0001-6846-888X>

Pavlo Zhuchenko

PhD in Medical Sciences, Associate Professor
National Pirogov Memorial Medical University
21018, 56 Pyrohova Str., Vinnytsia, Ukraine
<https://orcid.org/0000-0002-3448-1792>

Abstract. The heart valve design is optimally adapted to their physiological function, i.e., the uniform distribution of blood flow in the heart chambers, so even small changes in the structural components of the valves, which are initially functionally compensated, play a significant role in the development of heart disease in the later stages of a patient's life. The study aimed to determine the effect of chronic haemodynamic trauma on the structural reorganisation of human heart valves. A total of 1377 human heart valves were evaluated, which were obtained during valve prosthetics at the Amosov National Institute of Cardiovascular Surgery from 2010 to 2022. The study identified a full range of macro- and microscopic changes in morphological structures that are characteristic of rheumatic heart disease, infective endocarditis, dysplastic and destructive changes in heart valves. The set of all morphological features was combined into the algorithm "Morphological manifestations of acquired heart disease of different genesis". It has been established that changes in the mitral valve architecture can cause the transformation of its structural components, which causes a violation of the valve's functional capabilities. The study demonstrated that persistent changes associated with chronic haemodynamic injury reduce the mechanical strength of the valve, despite the compensatory mechanism of subendothelial smooth muscle fibre hyperplasia in the heart valve leaflets. Subsequently, these damages can, on the one hand, be complicated by fibrosis, fatty degeneration and calcification, and on the other hand, compensatory mechanisms are involved in the process, namely hyperplasia of subendothelial muscle cells, which often form continuous layers that should strengthen and strengthen the mechanical strength and thus the functional competence of the valves. Mitral valve dysplasia can develop secondary infective endocarditis, rheumatism, and degenerative valve disease. The algorithm for determining the patterns of morphological changes in the valvular apparatus of the heart in various

Suggested Citation:

Fedoniuk L, Rudenko O, Ruzhytska O, Zhuchenko P. Morphological changes in structural components of human heart valves associated with chronic haemodynamic trauma. *Bull Med Biol Res.* 2024;6(1):73–85. DOI: 10.61751/bmbr/1.2024.73

*Corresponding author



variants of acquired defects of inflammatory and non-inflammatory genesis can be used to improve the etiopathogenetic drug treatment of patients with acquired heart disease, as well as a theoretical basis for the development of new types of valve-preserving operations

Keywords: morphological changes; cardiac valve system; haemodynamic trauma; light microscopy

◆ INTRODUCTION

The heart valves are in constant motion, performing the function of a gate valve, which is associated with changes in internal cardiac blood pressure. Therefore, they must be sufficiently elastic and at the same time have a significant margin of safety [1, 2]. The architectonics of heart valves is optimally adapted to their physiological function – the distribution of intracardiac blood flow. This is ensured by the peculiarities of the structural organisation of the valves, namely, the outer dense layers of the valve leaflets separated by a thin loose spongiosis layer are complementary to the directions of intracardiac blood flow, as confirmed by S.D. Chen *et al.* [3]. Violation of this complementarity can cause damage to the structural components of the valves, and then secondary changes in the systolic and diastolic function of the heart [4], causing the development of both congenital and acquired heart disease (AHD). B. Zebhi *et al.* [5], S. Kraler *et al.* [6], and M. Chernykh *et al.* [7] have shown that in case of changes in the structure of valve structures, their complementarity concerning the hydrodynamic effect of blood on them may be disturbed with a change in the mechanical load on the entire valve or its parts and, possibly, with damage to some structures of the heart valves. Therefore, even small congenital changes in the structure of the valves, which are initially functionally compensated, can significantly contribute to the development of heart disease at later stages of a patient's life [8]. Modern literature reviews indicate that in the case of severe congenital pathology, the initial dysfunction leads to early clinical manifestation of heart disease and, in favourable cases, to its surgical resolution [9, 10].

According to Ukrainian researchers, the proportion of rheumatic endomyocarditis as a cause of AHD requiring surgical treatment decreased from 56% to 31.4% between 2009 and 2021 [11], which is attributed to improved prevention of rheumatic diseases, and on the other hand, a decrease in the immunological status of the Ukrainian population. At the same time, a decline in immunity contributes to an increase in the number of cases of acute infective endocarditis (IE), which causes valve destruction and the formation of valve failure. According to I. Karavanska [12], the incidence of IE in different regions of Ukraine ranges from 20 to 70 per 1,000,000 population per year. However, even in the treatment of patients with NSTEMI of known aetiology, questions sometimes arise that cardiologists cannot provide a convincing answer to. For example, it remains unclear why a valvular heart disease acquired as a result of an active rheumatic process, after a certain period of remission, begins to show signs of increasing haemodynamic disorders without signs of rheumatic activation. Local changes in the valves that contribute to the development of the so-called primary infective endocarditis are unclear.

These problems cannot be solved only by clinical methods, so they need to be studied using morphological techniques that will allow to assessment of the nature

and degree of pathological transformation of various valve structures, in particular the endothelium and connective tissue structures of valve leaflets and chords in AHD of various etiologies, which is important due to the fibrous framework of the valve ensuring its mechanical strength and elasticity, and, accordingly, the performance of the main functions of the valve. In the vast majority of scientific studies, there is no comprehensive approach to the study of the peculiarities of the organisation of structural components of heart valves in acquired pathology, and this aspect of the development of cardiac pathology is still poorly understood and insufficiently described. Therefore, the purpose of the study was to investigate the features of morphological changes in heart valves that occurred as a result of hemodynamic trauma.

◆ MATERIALS AND METHODS

The study examined 1,377 human heart valves received during valve replacement surgery at the Amosov National Institute of Cardiovascular Surgery from 2010 to 2022. Among them were 556 mitral valves (MV), 478 aortic valves (AV), and 343 tricuspid valves (TV). Among the patients were 925 men and 452 women, aged 8 to 76 years (mean age – 43.2 ± 11.6 years). The material for the study was collected in compliance with ethical and legal standards and requirements for scientific morphological studies [13].

The surgical material was examined macroscopically and microscopically. From the most and least damaged areas of the heart valves, pieces of leaflets or flaps were cut from the right or left fibrous ring to the edge, and the affected tendon strings were removed. Frozen sections were made from part of the material, which was stained with haematoxylin-eosin and Giemsa III-IV to identify fat-containing structures.

The rest of the material from similar valve areas was dehydrated in an alcohol bank of ascending concentration and paraffin-embedded at 640°C . Serial histological sections of 5–8 μm thickness were made on a sled microtome, after which the deparaffinised preparations were stained with haematoxylin-eosin. The conditions of collagen fibres were assessed by staining the sections with Van Gieson's picrofuchsin. Elastic fibres were selectively detected with fuchsin by Weigert. Fibrin of various degrees of maturity and blood cells were detected using the MSB (Marsch-Scarlet-Blue) technique in the Zerbino-Lukasevich modification [14, 15].

Light microscopy of histological sections, digital image processing and photographic documentation of the material was performed using a video image analysis unit CX-41 (OLYMPUS, Japan). The macroscopic examination of the heart valves assessed the thickness, density, and types of deformation of the leaflets (L), crescentic valves (CV), the overall degree of fibrosis, as well as fibrosis of adhesions and lines of closure of the leaflets, attention was paid to

the presence or absence of calcifications, warts, erosions, ulcers, abscesses, perforations, aneurysms, vegetations, haematomas, lipid stains, as well as signs of oedema and hyperaemia in various valve structures. Furthermore, the condition of the papillary-trabecular apparatus was studied in the MV: the length of tendon strings, the presence of tears, the degree of fibrosis, and the presence or absence of signs of dysplasia.

Microscopy of histological preparations of heart valves was performed consistently to assess morphological changes in structural components. In describing the surface of the heart valve leaflets/CV, the presence or absence of the endothelial layer, the condition of endothelial cells, and signs of their dystrophy, desquamation, and proliferation were noted. In the dense layers of the L/CV valves, the presence or absence of fibrosis, calcification or necrosis was assessed, including the presence of scars, collagen and elastic fibre bundles, and their fragmentation. The condition of the infiltrate cells was assessed: the presence or absence of morphological signs of dystrophy and the degree of their severity. The presence or absence of cholesterol crystals and proliferating smooth muscle cells was of particular importance. When describing the spongiosal layer of the L/CV of heart valves, its thickness, presence or absence of hematomas, cholesterol crystals, morphological signs of oedema, as well as the state of connective tissue fibres (their fragmentation, collagen cords from dense layers, fibroblast proliferation, fatty transformation, fibrosis and calcification of varying degrees) were determined. Similarly to the dense layers, signs of cellular infiltration were recorded by the presence of neutrophils, histiocytes, lymphocytes, macrophages and lipophages.

The condition of blood vessels was determined by their wall thickness, lumen size, presence or absence of fibrinoid necrosis, leukocyte infiltration, destruction, fibrosis and hyperaemia in their membranes.

At the initial stage of the study, a complete set of variants of macro- and microscopic changes in morphological structures characteristic of rheumatic heart disease, infective endocarditis (IE), dysplastic and destructive changes in heart valves was determined. The set of all morphological features was combined into the algorithm "Morphological manifestations of AHD of different genesis".

The statistical processing of digital data was carried out in the environment of a licensed copy of the Excel computer program (version XP, Microsoft® Corp.) by programming the appropriate calculation algorithms with their subsequent processing. For the analysis of the results, one of the MS Office applications, the spreadsheet processor MS Excel 2003, was chosen for statistical analysis necessary for further discussion of the results, finding the minimum and maximum values, the mean and standard error of measurements, and determining the level of reliability.

RESULTS

The creation of the algorithm "Morphological manifestations of AHD of different genesis" determined a complete list of structural changes in heart valves of different aetiologies. In particular, when assessing the physical parameters of morphological changes in the L MV and CV AV of the heart, it was found that in 94.8% of cases of dysplasia, their area increased, which was not observed in any observation in IE-I and AHD (Table 1).

Table 1. Frequency of L and MV physical changes in various forms of AHD

No.	Morphological changes	AHD forms, %						Total n = 1,377
		AR n = 209	HA-PM n = 375	IE-I n = 190	IE-II n = 105	VD n = 207	RC n = 291	
1.	Expanded surface	11.5	23.7	0	19.2	94.8	0	28.5
2.	Reduced surface	0	0	79.6	72.3	7.4	0	17.4
3.	Thickened L or CV	100	100	42.8	61.7	90.2	68.5	85.1
4.	Thinned L or CV	0	0	58.1	38.3	9.8	8.3	14.7

Notes: CV – crescentic valves; AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – structural valve dysplasia; RC – regression changes

Source: compiled by the authors

In rheumovallulitis, the L/CV surface was increased by 23.7% maximum of observations and was never reduced. Reduction of their leaflet area was a characteristic morphological sign of IE. For AHD of noninflammatory genesis, reduction of the area of the L/CV was also not typical, although it was found in 7.4% of cases of heart valve dysplasia. The thickness of the leaflets increased due to fibrosis and calcification in 100% of observations in patients with rheumovallulitis, and in the active stage of the disease – also due to oedema. In IE-I, they were both thickened due to the presence of oedema and vegetation of the L or CV (41.9%) and thinned due to the dominance of lytic processes (58.1%).

In AHD that developed due to subclinical forms of valve dysplasia, in 90.2% of observations, the L/MV was

thickened due to either calcification or oedema of the spongiosal layer. In 68.5% of AHD cases, the leaflets or MV were also thickened as a result of coarse calcifications; 8.3% of leaflets or CV had atony and thinning due to widespread fatty regression of their connective tissue structures; in the remaining 23% of valves in this group, the thickness of the leaflets or CV was slightly changed, although foci of slight yellow-orange thickening were observed under the endothelial layer. In IE-II, L or CV in the area of adhesions and marginal sections were thickened only in those patients with a history of rheumatic heart disease (17.0%).

In valves with dysplasia due to calcifications surrounded by fibrous capsules (44.4%), L or CV were usually thickened and dense, in other cases – soft, sometimes

swollen. Calcification also determined the high density of 56.1% of valves in RC AHD. Of this group, 7.7% of the L or CV valves appeared soft, atonic, thinned, sometimes with a finely ribbed surface relief. In general, among 1377 observations, valves with dense (59.7%) and thickened L or CV were the most common. Moreover, if the density was determined mainly by fibrosis and calcification, the increase in thickness could also be caused by significant oedema and overlapping vegetation. Features of morphological

macroscopic signs in the removed valves were also determined by the presence of erosions, ulcers, oedema, foci of hyperaemia and perforations (Table 2). Erosions of various sizes and shapes appeared as loose areas without the typical lustre of surfaces, and sometimes their edges were exfoliated. Erosions were detected in the majority of observations of inflammatory AHDs, as well as in 28.3% of cases of valve dysplasia and 28.9% of valves removed for RC heart disease. In total, erosion was detected in 71.4% of cases.

Table 2. Frequency of macroscopic erosions, ulcers, oedema, hyperaemia, vegetations, lipid stains, haematomas, abscesses, warts and aneurysms of valve structures in different AHD forms

No.	Morphological feature	AHD forms, %						Total n = 1,377
		AR n = 2,097	NAR n = 375	IE-I n = 190	IE-II n = 105	VD n = 07	RC n = 291	
1.	Erosions	88.8	91.1	100	100	28.3	28.9	71.4
2.	Ulcers	77.8	86.5	100	100	23.5	13.1	70.2
3.	Oedema	84.0	0	100	100	89.6	34.5	54.3
4.	Hyperaemia	31.8	0	82.6	90.3	0	0	22.2
5.	Vegetations	0	0	100	100	0	0	21.7
6.	Lipid spots	60.8	92.6	0	72.8	73.1	88.9	73.1
7.	Warts	100	95.7	17.4	83.6	88.4	15.5	72.6
8.	Haematomas	6.4	2.3	0	22.5	0	0	4.3
9.	Abscesses	0	0	26.8	33.8	0	0	5.0

Notes: AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – valve dysplasia; RC – regression changes

Source: compiled by the authors

In 70.2%, ulcers were detected, which most often formed over large calcifications, forming tissue defects up to 2 cm in diameter. Such ulcers usually had a calcified bottom, which was imbibed with blood and covered with fibrin clots. Ulcers were observed in the area of fibrous adhesions and the absence of calcifications. In these cases, the tissue defect had a linear shape in the direction from the fibrous ring of the valve to its lumen. In IE, deep damage to the L structures was caused by tissue lysis, which was present in 100% of observations.

A sign of L/CV oedema was recorded in 54.3% of cases. In AR, oedema of the surface layers of the structural components of the valves was manifested by their swelling and translucent appearance. The fibrous tissue of the deeper layers also swelled and became less dense and compact. No signs of oedema were present in NAR. In IE, as in other inflammation, oedema occurred in 100% of cases. The valve leaflets with signs of dysplasia often (85.6%) had a myxomatous appearance: diffuse throughout or in some areas. Their middle layer increased in volume and became almost transparent and slippery to the touch. Hyperaemia of the L/CV occurred only in the active inflammatory process: in 31.8% of cases of active rheumovulvitis, as well as in EI-I and EI-II (82.6% and 90.3%, respectively). As it turned out, vegetations are a pathognomonic sign of EI. They were detected in all cases of both EI-I and EI-II and were not recorded in other pathological processes.

A yellow-orange lipid stain located under the endothelium in the areas subjected to the greatest haemo-

dynamic load was a frequent finding (72.2% of all observations) in the macroscopic examination of heart valves. They were present in 60.8% of valves with AR, 92.6% of inactive valves, 73.1% of IE-II observations, 73.1% of valves with dysplasia, and 88.9% of cases of RC AHD. This was absent only in IE-I.

The growth of loose fibrous connective tissue in the form of warts along the edges of the L and CV, as well as in areas of relief altered by fibrosis and calcification, was found in all groups: most often in rheumovulvitis (100% of observations of active rheumatic process and 95.7% of inactive rheumatic process), EI-II (83.6%) and heart valve dysplasia (88.4%). In the case of dysplasia and RC of their structures, warts were detected much less frequently (17.4% and 15.5%, respectively).

In only 4.1% of cases, haematomas were observed in the damaged L and CV. They were most often recorded in EI-II (22.5%), less often in active rheumovulvitis (6.4%), and even less often (2.3%) in inactive rheumocarditis. In the other groups, haematomas were not observed. Similarly to vegetation, macroabscesses were a pathognomonic feature of IE. They were not formed in every case of IE. In particular, macroabscesses were detected in 26.8% of IE-I, and 33.8% of IE-II. Macroabscesses were not observed in other forms of IE. Therefore, the detection of vegetation and abscesses in the heart valves can reliably testify in favour of IE. In the study of MV, special attention was paid to the condition of the tendon strings of the papillary-trabecular apparatus of the heart (Table 3).

Table 3. Frequency of detection of macroscopic changes in tendon strings of the MV in various forms of AHD

No.	Morphological feature	AHD forms, %						Total n = 1,377
		AR n = 209	NAR n = 375	IE-I n = 190	IE-II n = 105	VD n = 207	RC n = 291	
1.	Normal length TS	27.1	22.1	100	71.6	8.1	92.8	43.6
2.	Long TS	15.6	16.0	0	7.8	78.6	5.7	23.1
3.	Short TS	64.2	65.3	0	23.1	25.6	0	34.9
4.	Fibrosis 0	0	0	100	65.0	11.1	100	35.8
5.	Fibrosis 1+	48.9	22.7	0	20.3	75.7	0	29.0
6.	Fibrosis 2+	52.2	74.6	0	14.6	11.1	0	34.3
7.	Dysplasia	0	2.7	0	26.9	100	0	21.1
8.	Tears	0	0	43.2	37.8	13.5	0	10.9

Notes: TS – tendon strings; AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – valve dysplasia; RC – regression changes

Source: compiled by the authors

It was found that only in IE-I, in 100% of observations, tendon string lengths were unchanged. In IE-II, this figure was 71.6% and in RC AHD – 92.8%. In AR and NAR, as well as in valve dysplasia, tendon strings of normal length were found much less frequently: 27.1%, 22.1% and 8.1%, respectively. Moreover, in dysplasia, both elongated (78.6%) and shortened tendon strings (25.6%) could be found in the same valve.

In rheumatism, short tendon strings of the MV were most common: in AR they were recorded in 64.2%, and in active rheumatism – in 65.3%. Long tendon strings were differentiated in only 15.6 % of AR and 16.0% of NAR. In IE-II and RC AHD, L with long tendon strings were relatively rare: 7.8 % and 5.7 %, respectively. Shortening of tendon strings in IE-II (23.1%) was due to initial post-stroke fibrosis or fibrosis associated with papillary trabecular apparatus dysplasia since in these groups of patients fibrosis of tendon strings, as well as of the cusps, was the

most common: in dysplasia – 88.9%, NAR and AR – 100%. It should only be noted that in rheumovallulitis, valves with gross fibrosis dominated, whereas in papillary-trabecular dysplasia, not all tendon strings were affected by fibrosis and the degree of fibrosis was moderate in most cases (75.7%). Fibrosis of tendon strings was not typical for valves with RC AHD.

Signs of congenital abnormality of the papillary-trabecular apparatus of the MV were detected in 100 % of valves in the dysplasia group, as well as in 26.9% of valves with IE-II and 2.7% of observations of inactive rheumovallulitis. Signs of tendon string rupture were not recorded in any case of rheumovallulitis and RC AHD, but signs were found in IE-I (43.2%), IE-II (37.8%) and papillary-trabecular dysplasia (13.5%). A detailed microscopic examination of the structural components of the heart valves revealed that their surface was in no case intact throughout, the endothelium was damaged (Table 4).

Table 4. The frequency of detection of valve endothelial changes in various forms of AHD

No.	Morphological feature	AHD forms, %						Total n = 1,377
		AR n = 209	NAR n = 375	IE-I n = 190	IE-II n = 105	VD n = 207	RC n = 291	
1.	Normal surface	0	0	0	0	0	0	0
2.	Erosions	88.5	93.3	100	100	96.5	80.9	93
3.	No endothelium changes	0	0	0	0	0	0	0
4.	Endothelium exfoliated	88.8	97.4	100	100	96.4	100	97.1
5.	Endothelial dystrophy	77.4	27.5	100	100	71.3	61.8	63.2
6.	Endothelial proliferation	0	0	0	0	23.2	33.2	8.9

Notes: AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – valve dysplasia; RC – regression changes

Source: compiled by the authors

In IE-I and IE-II, as well as in RC AHD, endothelial desquamation was found in 100% of observations. Somewhat less frequently, in 88.8 – 97.4% of cases, this morphological sign was present in active and inactive rheumovallulitis and AHD associated with heart valve dysplasia.

Various signs of endothelial dystrophy were found in an average of 63.2% of observations, with IE causing endothelial dystrophy in 100%. In NAR, areas with dystrophically altered endothelial layer were detected in 27.5% of patients, in the other groups this sign

was noted in 77.4% of AR, in 71.3% of valve dysplasia and 61.8% in RC AHD. In noninflammatory AHD, signs of increased endothelial cell proliferation were sometimes observed on the surface of the valve leaflets: in

valve dysplasia in 23.2%, and RC in 33.2%. Endothelial damage was often accompanied by significant changes in the dense surface layers of the L and CV of the heart valves, as shown in Table 5.

Table 5. Frequency of detection of necrotic and fibrotic changes in connective tissue structures of dense layers in various forms of AHD

No.	Morphological feature	AHD forms, %						Total n = 1,377
		AR n = 209	NAR n = 375	IE-I n = 190	IE-II n = 105	VD n = 207	RC n = 291	
1.	Fibrinoid necrosis	100	16.2	4.8	16.1	0	0	20.3
2.	Enzymatic lysis	0	0	100	100	0	0	56.7
3.	Cholesterol necrosis	59.8	90.5	0	50.7	59.5	100	68.7
4.	Scars	100	100	0	56.4	0	0	51.1
5.	Fibrosis	37.8	36.8	0	53.2	45.6	68.7	42.1
1.	Smooth muscle cell proliferation	1.7	3.2	0	20.4	84.6	0	19.1
2.	Loosening of layers	0	0	0	9.4	83.0	0	16.5
3.	Collagen fibre fragmentation	0	0	0	8.6	66.3	0	12.8
4.	Intercellular substance accumulation	100	0	14.3	11.2	68.9	29.2	30.5
5.	Calcification	100	100	33.2	54.3	63.8	68.9	77.5

Notes: AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – valve dysplasia; RC – regression changes

Source: compiled by the authors

Thus, in AR, signs of fibrinoid necrosis of connective tissue structures of dense surface layers of the L and CV of heart valves were detected in 100% of observations. In NAR, fibrinoid necrosis was detected in histological specimens in only 16.2% of patients, but in these cases, fibrinoid necrosis showed signs of calcification in the central parts of the lesions and fibrosis in the periphery. Changes in collagen structures characteristic of fibrinous necrosis were sometimes also found in IE, and in IE-II - much more often than in IE-I: 16.1% vs. 4.8%. It was noteworthy that foci of fibrinous necrosis were often located around the blood vessels away from the main focus of valve damage in subacute and recurrent forms of IE. In NAV of noninflammatory origin, classical manifestations of fibrinous necrosis were not observed in any case. However, these valves showed zones of collagen homogenisation, which, unlike eosinophilic fibrinoid necrosis, usually had a slightly basophilic colour. Necrosis of the dense layers of the L and CV of the heart valves, which was caused by the lytic action of neutrophil lysosomal enzymes and microbial waste products, was pathognomonic for both groups of IE. This morphological sign was found in 100% of observations in IE, whereas in other forms of AHD, necrosis of the dense layers of the L and CV of the valves was absent.

The most frequent morphological sign (68.7%) in all material was cholesterol necrosis, which gave a positive sudan III-IV stain and was often accompanied by the presence of lipophages and cholesterol crystals. Such changes were recorded in 100% of observations in RC AHD, in 90.5% in NAR, in 50-60% in AR, IE-II and valve dysplasia. IE-I was included in this group only in the absence of other morphological changes, including cholesterol necrosis. Gross scarring deformation of the dense surface layers of the L and CV along the line of their closure, in the area of adhesions, as well as tendon strings of the MV, was detected in all cases of AR and NAR. At the same time, the central parts

of the L and CV were fibrosed much less. In 56.4 % of cases of IE-II, these changes developed against the background of scarred valve structures. In IE-I and AHD of non-inflammatory genesis, scarring changes in the heart valves were usually not detected. However, quite often in the latter two groups, there was a diffuse increase in the fibrous component of the dense layers of the L and CV: in the initial valve dysplasia – in 45.6%, in the RC AHD group – in 68.7%. Fibrosis of the valve structures without disturbance of collagen fibre orientation was also detected in 37.8% of A-RM cases, 36.8% of NAR cases and 53.2% of observations in IE-II. It should be noted that fibrosis without scarring changes was usually localised on the periphery of the main foci of fibrosis and calcification.

Other morphological changes were often detected in the surface layers of the L and CV, in particular, in 19.1% of observations, a peculiar subendothelial layer of smooth muscle cells, which is not characteristic of normal heart valves, was differentiated in histological preparations of heart valves. Most often (84.6%) it was detected in the L and CV with signs of dysplasia. In IE-II, this morphological sign was present in 20.4% of cases, in AR – only in 1.7%, and in NAR – in 3.2% of cases. The subendothelial layer of smooth muscle cells was not detected at all in IE-I and in RC of the heart.

There are two morphological signs (thinning of the dense surface connective tissue layers of the L and CV and fragmentation of collagen fibres), which were largely observed only in congenital heart valve disease (83.0% and 66.3%, respectively), as well as in IE-II, which developed against the background of valve structure dysplasia (9.4%, 8.6%). Swelling of the connective tissue due to the accumulation of intercellular substance in it was recorded in the dense surface layers of the L and CV in all cases of AR, in 14.3% of cases of IE-I, in 11.2% of observations of IE-II, in 68.9% of cases – in the L and CV of heart valves with initial dysplasia and 29.2% of valves with RC of their structures.

Calcification of the heart valve structures was one of the most frequent morphological features (77.5% of cases). Moreover, in both groups of rheumatic fever, calcification was found to a greater or lesser extent in all valves. Calcification was detected in 63.8% of patients with non-inflammatory AHD, in patients with valve dysplasia and 68.9% of patients with RC AHD. In patients with IE, calcification in the thickness of fibrotic altered valve structures was detected only in IE-II. In addition, a feature of infectious valvulitis was the presence of calcium in the vegetation. It was this localisation of calcification that led to 33.2% of observations of this sign in patients with IE-I. In patients with IE-II, calcification was observed in 54.3%.

In addition, the presence of nuclear detritus was noted, which was present in 100% of IE-I and IE-II observations and was completely absent in other forms of AHD. When assessing the spongiosis layer of the L and CV of the heart valves, its thickness was prioritised (Table 6). In rheumatic malformations, this layer was rarely dilated and often not differentiated at all due to severe fibrosis. In IE-I, in the L and CV, namely in areas that were not destroyed by lysis and massive cellular infiltration, the spongiosis layer was found to be expanded in 85.4% of cases, and in IE-II only in 45.9%. Different types of valve dysplasia were accompanied by diffuse or focal expansion of the spongiosis layer in 100%. In RC AHD, this sign was present in 38.5%.

Table 6. The frequency of detection of morphological changes in the spongiosal layer in various forms of AHD

No.	Morphological feature	AHD forms, %						Total n = 1,377
		AR n = 209	NAR n = 375	IE-I n = 190	IE-II n = 105	VD n = 207	RC n = 291	
1.	Expansion	0	0	86.4	45.9	100	38.5	38.4
2.	Oedema	28.2	0	85.4	0	100	38.5	36.3
3.	Fragmentation of connective tissue fibres	0	0	0	0	97.2	0	18.1
4.	Collagen cords from dense superficial layers	0	0	0	17.3	74.2	0	16.4
5.	Fat transformation	0	0	0	0	47.8	13.0	10.8
6.	Fibrosis	100	100	0	68.4	31.4	43.9	65.1
7.	Calcification	81.3	100	45.1	53.2	17.5	46.9	62.9

Notes: AR – active rheumatism; NAR – non-active rheumatism; IE-I – initial infective endocarditis; IE-II – secondary infective endocarditis; VD – valve dysplasia; RC – regression changes

Source: compiled by the authors

Spongiosal oedema was detected in 28.2% of valves in AR, in 86.4% of IE-I observations, and 100% of specimens obtained from valves with signs of dysplasia. Primary RC of the L and CV were accompanied by oedema of the spongiosal layer in 38.5% of cases. Heart valves with subclinical forms of congenital pathology were characterised by fragmentation of connective tissue fibres of the spongiosal layer (97.2%), spread of collagen fibre strands from the dense surface layers of the L and CV (74.2%), and transformation of loose fibrous connective tissue of the spongiosal layer into adipose tissue, which was recorded in 47.8% of cases.

In other AHD forms, these morphological signs were almost always absent, only 17.3% of IE-II showed collagen fibre disruption of dense layers and 13.0% of RC AHD had fatty transformation of the spongiosal layer. Fibrosis of the spongiosis layer of the L and CV of the heart valves was noted in 100% of rheumovallulitis, both active and inactive, in 68.4% of observations in IE-II, in 31.4% of cases in patients with cardiac valvular dysplasia and 43.9% in patients with RC AHD. Calcification of the L and CV of the heart valves extended to the spongiosis layer with greater or lesser frequency in all groups of observations: in active rheumovallulitis – in 81.3% of observations, in NAR – in 100% of cases, in IE-I – in 45.1%, in IE-II – in 53.2% of observations, in dysplasia – in 17.5%, in AHD heart disease – in 46.9% of cases.

The analysis of the frequency of macro- and microscopic changes in heart valves allowed us to identify several morphological features that are detected with varying degrees of probability in AHD of various genesis. This made

it possible to carry out morphological diagnostics of the morphogenesis of acquired heart valve defects, as well as to verify the nosological affiliation of the AHD for which patients were operated with maximum objectivity.

AV Bicuspid was an AV defect. The macroscopic characteristics of this pathology are well known and consist of an increase in the thickness of one of the valves, in the centre of which crestal transverse thickenings were usually detected. According to the results of light microscopy, AV calcification developed as a consequence of fatty degeneration of the connective tissue, which was detected even in patients under the age of 20 (Fig. 1).

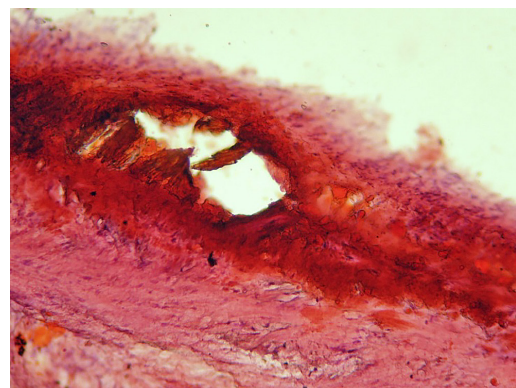


Figure 1. Bicuspid AV; fatty degeneration, calcification. Sudan III-IV. x40
Source: compiled by the authors

In addition, the aortic surface of such a valve was finely ribbed, with small areas of irregular fibrosis and sometimes with thinning, up to leaflet tears, which were usually oriented parallel to the thickened layer due to fibrosis and translucent overlays in the form of warts. Macroscopic characteristics of congenital MV pathology consisted mainly of dysplasia of the papillary-chordal apparatus, which was manifested by irregular arrangement of tendon strings, decrease or increase in their number, and changes in their thickness, length and direction. This resulted in the pulling of one or more heads of papillary muscles to the valves and lengthening of others with their subsequent fibrosis. There was uneven swelling of the valves, their deformation due to the formation of aneurysm-like protrusions towards the atrium. Such changes were noted in areas that were not supported by tendon strings. The edges of the heart valve leaflets had a fistulous appearance, and translucent growths in the form of warts were localised on them.

Microscopic examination of the heart valves obtained at autopsies showed that the L TV and pulmonary trunk valves had a normal structure with a clear parallel orientation of collagen fibres and preserved endothelium. The surface dense layers of the aortic valve were unchanged in the CV, with a parallel orientation of intact collagen fibre bundles, and moderate oedema of the CV spongiosal layer without specific signs of inflammation. Light microscopy in the L MV of the heart MVs showed a significant expansion of the middle spongiosal layer due to its oedema, as well as stratification of collagen fibre bundles of the dense outer layers of the L, and moderate fibroblast proliferation in the spongiosal layer.

In the base of the Valsalva sinuses in the CV aortic valve leaflet, smooth muscle proliferation occurred in dysplasia of its structures, as well as in MV dysplasia. Since a particularly pronounced disorganisation of the connective tissue fibres of the valve with a sharp swelling and expansion of the spongiosis layer, as well as loss of compactness of the surface dense layers was observed, smooth myocyte layers often looked like single compact areas in this part of the V or CV. At the same time, valves were often observed with further proliferation of young connective tissue and transformation of loose fibrous connective tissue into adipose tissue, which reduced the mechanical strength of the valve (Fig. 2).

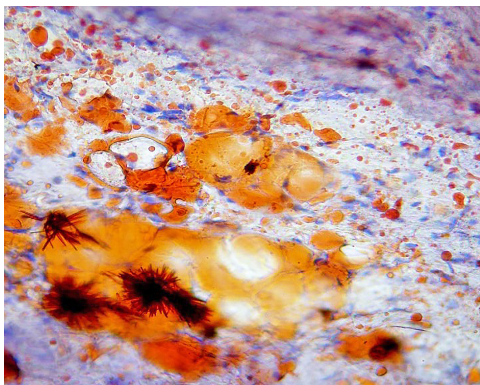


Figure 2. Fatty transformation of the spongiosis layer. Sudan III-IV. X 200

Source: compiled by the authors

In the areas of the leaflets without mechanical support of tendon strings, whole layers of hyperplastic sub-endothelial smooth muscle fibres were naturally detected, which can be considered as a compensatory reaction of the body aimed at enhancing the reduced mechanical properties of the heart valve leaflets (Fig. 3).

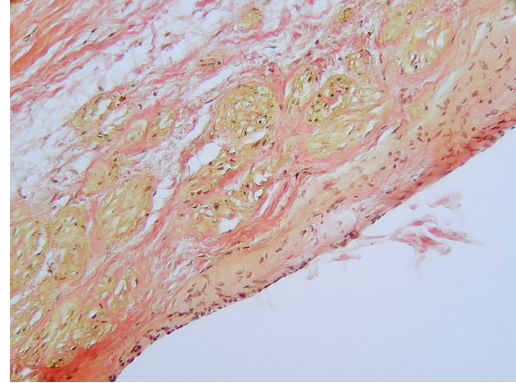


Figure 3. MV dysplasia, compensatory hyperplasia of subendothelial smooth muscle fibres.

Hematoxylin-eosin. X 100

Source: compiled by the authors

In patients aged 28 ± 5.3 years, homogenisation of the CV surface layers was observed in some areas of the aortic valve leaflet. At the same time, the layer in the corresponding area expanded, swelled and acquired a slightly basophilic tint with a loss of fibrous connective tissue structure. Subsequently, calcium was deposited in these areas, which led to pronounced deformation of the valve flap. Focal homogenisation of one of the dense surface layers was accompanied by the narrowing of the dilated spongiosis layer and disorganisation of connective tissue structures of the dense surface layer of the opposite side. In patients aged 37 ± 7.4 years, calcification became the dominant morphological sign of the disease.

All the changes described above can be attributed to chronic haemodynamic trauma to the valve structures. Until a certain point, these changes had no clinical manifestations. However, they can be considered factors that create prerequisites for the development of more severe pathological processes that give rise to certain clinical symptoms. In particular, areas of the valves without a protective endothelial layer are often the entrance gate for infection, which leads to the development of heart valve IE [16].

In addition, MVs with subclinical forms of congenital pathology are early exposed to RC [17]. In this case, endothelial exfoliation occurred, areas of the damaged surface with signs of active fibrogenesis were detected, and connective tissue fibres within the leaflets were homogenised, infiltrated by fat cells and calcified, which led to rapid decompensation of the valve defect. In addition, the deendothelialised surface areas were covered with a thin layer of fibrin, in which lymphocyte cells were localised, and signs of endothelial cell proliferation were still detected on the surface of some areas. This was true for both areas with damaged surfaces (Fig. 4) and internal connective tissue structures that were subjected to particularly high mechanical stress.

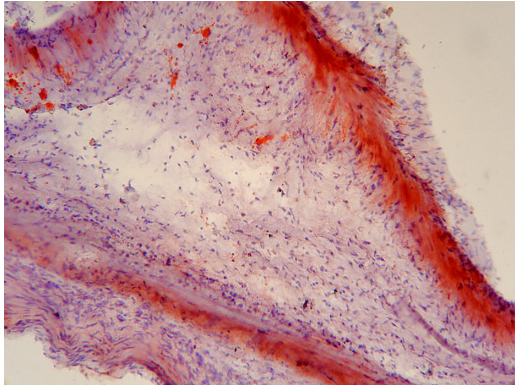


Figure 4. MV dysplasia. Sudanophilic degeneration of connective tissue structures of L Sudan III-IV. X 40
Source: compiled by the authors

Among the 556 MVs studied, it was noted that in 126 patients (22.7%), congenital valve disease began to be detected in adulthood, even without concomitant pathology. This was the group of the youngest patients with severe primary dysplasia. In 45 patients, valve dysplasia was complicated by IE. In 39 cases, signs of congenital MV pathology were detected in poststroke valvular fibrosis and calcification. The largest group consisted of patients with valve dysplasia combined with severe degenerative changes in connective tissue structures. In 285 cases (51.2%), lipoidosis with calcification was the only factor that complicated the initial dysplasia. However, in 61 patients, more than two etiopathogenetic factors were noted (lipoidosis and EI or lipoidosis and rheumatism).

The group with significant RC signs consisted of patients of more mature age (48.2 ± 9.3 and 46.6 ± 11.7). However, the age of patients whose valves were affected by a degenerative process without underlying dysplasia was also investigated and found to be 60.8 ± 14.5 years, which is significantly higher than the age of patients with degenerative valve disease that developed on the background of MV dysplasia. Thus, changes in the structural organisation of heart valves associated with chronic haemodynamic trauma affect the functional capacity of the valve.

DISCUSSION

Modern methods of clinical and instrumental diagnostics allow to establishment of the mechanical characteristics of the defect (stenosis or insufficiency), determine the severity of the valvular lesion, the presence and severity of haemodynamic disorders [18]. The mechanical functions of damaged valves are currently restored by surgical correction of the defect, including valve prosthetics. However, to determine adequate pre- and postoperative drug treatment regimens for patients, it is also important to establish the aetiology of the defect (rheumatism, infective endocarditis, dystrophic changes, coronary heart disease, etc.), and in the presence of a systemic inflammatory process, its activity.

AHD is caused by a variety of pathological processes, most of which have certain morphological characteristics that allow distinguishing the processes from each other [19, 20]. At the same time, many years of experience

in the morphological study of heart valves removed for AHDs have shown that histological specimens often reveal features that have not received much attention from researchers [21, 22].

According to the authors of this study, which is also confirmed by the studies of other researchers [23, 24], in most cases, the AHD was localised in the valves of the left heart (MV and AV), which is associated with the greatest mechanical load on these valves, as high blood pressure is created here. Only recently have there been defects in the AHD in which the tricuspid valve is involved in the pathological process. This is associated with infective endocarditis in drug addicts, as well as in people who have undergone various intravenous manipulations.

Haemodynamic disorders that occur in AHD are caused by changes in the macro- and microarchitecture of heart valves [25, 26], structural reorganisation of the connective tissue components of the valvular apparatus [27] and endothelium. At the same time, the most vulnerable are the edges of the leaflets, the lines of leaflet closure, the pericommissural areas of the AV, MV, and TV, as well as the bases of the MC chords, i.e. the areas that are exposed to the greatest hemodynamic impact. According to O. Papuha [28], dynamic mechanical impact on the subject causes the accumulation of hyaluronic acid in the medium, which causes the homogenisation of collagen fibres. Static mechanical impact does not have this property.

The data obtained in the present study coincide with those of the authors who studied not only the structural organisation of heart valves but also the morphological causes of cardiac conduction disorders. According to M. Sugiura *et al.* [29], calcifications acting on the anatomical bifurcation of the bundle cause various conduction disorders, but the most observed blockade of the left or right pedicle or simultaneous blockade of the right pedicle and the anterior branch of the left pedicle, i.e. bifascicular block. In some cases, calcifications spreading beyond the fibrous ring of the aorta, towards the apex of the interventricular septum, gradually mechanically press on the relevant parts of the conduction system. In other cases, calcification spreads beyond the fibrous ring of the aorta by sprouting the muscular ridge of the interventricular septum, destroying the tendon strings, which occurs, for example, in rheumatic damage to the AV.

The significant role of haemodynamic trauma in the development of AHD is supported by the data of T.S. Momberger *et al.* [30], which show that it is the dynamic mechanical effect that stimulates the accumulation of hyaluronic acid in the interstitial tissue, which causes swelling of the interstitium and collagen fibres. Even minimal morphological changes of a congenital nature in heart valves lead to an increasing remodelling of heart valve structures, which is consistent with the data of E. Aikawa & J.D. Hutcheson [31]. The process of transformation of the valve leaflets occurs through morphological changes, namely fragmentation and stratification of collagen fibre bundles with swelling of the spongiosis layer. The surface of such valves, especially along the line of leaflet closure, at the base of the tendon strings of the MV and in the commissures, is damaged. All these changes are a consequence of the chronic mechanical effect of blood flow on the valve structures. Subsequently, these

damages can, on the one hand, be aggravated by fibrosis, fatty degeneration, and calcification, and on the other hand, compensatory mechanisms are involved in the process that improves mechanical strength and thus the functional capacity of the valves, namely, the authors of this paper consider hyperplasia of subendothelial smooth muscle cells to be a compensatory mechanism.

This study also examined a group of isolated abnormalities of valve structures (minimal forms of dysplasia) that did not impair valve function in the first decades of life and, accordingly, did not produce any clinical manifestations. When non-inflammatory NAV affects people of young and mature age, clinicians define the defect as idiopathic. This includes, for example, Barlow's disease, which occurs in 1.5-17% of the population [32]. However, after 20-30 years, according to the above studies, this pathology led to the early development of degenerative changes in connective tissue structures. Over time, the changes caused by dysplasia were complicated by calcification, and then clinicians diagnosed either calcifying heart disease or stenosing calcification. This pathology was manifested by significant haemodynamic disorders and required surgical correction.

However, many doctors consider age-related changes in heart valves (primarily in the AV) to be almost normal and do not pay attention to the appearance of a systolic murmur in the aorta when monitoring a patient. In addition, as a result of environmental changes and an increase in the prevalence of anthropogenic factors that accelerate the development of calcific heart disease, this disease began to occur at the age of 45-50 years [33]. At the same time, with age, small forms of valvular pathology acquire the character of a clinically significant process and are often mistakenly interpreted as infective endocarditis, rheumatism, etc. Thus, AHD occurs as a result of various factors that determine the development of morphological changes in the valvular apparatus of the heart, which are characteristic of each of the nosological forms.

However, the morphogenesis of the AHD contains elements that are common to all or most types of acquired defects. Specific features include fibrinoid necrosis, Ashof-Talalayev granulomas, productive-destructive vasculitis - in rheumatic heart disease; leukocyte infiltration with numerous neutrophils, lysis of heart valve structures, vegetations, abscesses - in IE; changes in the number of CVC valve leaflets, disorders of the architecture of the papillary-trabecular apparatus and MV leaflets, as well as compensatory hyperplasia of subendothelial smooth muscle cells - in AHD developing against the background of subclinical forms of valve dysplasia; age-related degenerative changes in connective tissue with lipoidosis and subsequent calcification - in AHD of degenerative genesis.

All heart valves are united by the fact that they are in the heart cavities and are subject to constant systolic and diastolic effects of intracardiac blood flow. Therefore, AHD is characterised by morphological changes associated with chronic haemodynamic trauma. In addition, the heart valves are constantly in direct contact with a large amount of blood, and therefore any damage to the endothelial layer provides access to the valve structures for lipids and peroxidation products that are present in the blood in varying amounts. Consequently, changes in

the architectonics of the MV lead to the transformation of its structural components, which causes a violation of the valve's functionality. Hemodynamic trauma with damage to the endothelial layer and lipoidosis of valve structures plays an important role in the formation of heart disease.

✦ CONCLUSIONS

Persistent changes in the architecture of heart valves lead to chronic haemodynamic injury, causing the transformation of structures with impaired valve functionality. Hyperplasia of subendothelial smooth muscle fibres in L valves with mild dysplasia can be regarded as a compensatory mechanism associated with the need to increase mechanical strength and thus the functional capacity of valves. MV dysplasia can lead to the development of IE-II, rheumatism, and RC heart valve disease. It should be noted that secondary valve deformation associated with rheumatic sclerosis or RC exacerbates hemodynamic injury and contributes to the morphogenesis of mitral heart disease.

A wide range of changes is recorded in the structures of the heart valves, which are present in varying degrees of severity in the case of AHD of different genesis. Signs of significant calcification were detected in 65.7% of non-inflammatory AHD, including 14.1 % of the defect associated with age-related degenerative changes in the connective tissue structures of the valve and 13.3 % with subclinical dysplasia. Dystrophic changes in the structures are manifested by homogenisation of collagen fibres with their subsequent fatty infiltration (in 100% of cases of degenerative AHD, 64% of cases of AHD with subclinical forms of dysplasia, 59.8% of cases of rheumatism and 51.1% of cases of secondary infective endocarditis), as well as fatty transformation of the loose connective tissue of the spongiosal layer. These changes are accompanied by lipophage accumulation and calcification. Morphological studies have established that, unlike acute rheumatic heart disease, in chronic active and inactive rheumatism, factors caused by chronic haemodynamic trauma to the deformed valves (fibrogenesis on the damaged leaflet surface in 100% of cases of active rheumatic heart disease and 97.8% of cases of inactive rheumatism), as well as degenerative changes in scar tissue, are involved in the formation of AHD. The intracardiac localisation of heart valves causes a constant haemodynamic influence of systolic and diastolic blood flows on their structures. At the same time, any changes in valve architecture cause absolute hemodynamic damage to the endothelium, which contributes to the development of AHD of various genesis and is manifested by morphological changes in endothelial cells with various types of damage. Thus, mechanical overload of valves in hemodynamic injury precedes the development of valve failure. Further morphological diagnostics of AHD will allow for accurate verification of the defect and the development of adequate postoperative treatment regimens.

✦ ACKNOWLEDGEMENTS

None.

✦ CONFLICT OF INTEREST

The authors declare no conflict of interest.

◆ REFERENCES

- [1] Semeniuk TO, Malyk YY, Pentelejchuk NP, Khodorovska AA. Micro- and ultramicroscopic structure of the left atrioventricular valvular apparatus in human at the mature age in norm. *Bukov Med Herald*. 2023;27(1):23–27. DOI: [10.24061/2413-0737.27.1.105.2023.5](https://doi.org/10.24061/2413-0737.27.1.105.2023.5)
- [2] Yang P, Tronccone L, Augur ZM, Kim SSJ, McNeil ME, Yu PB. The role of bone morphogenetic protein signaling in vascular calcification. *Bone*. 2020;141:115542. DOI: [10.1016/j.bone.2020.115542](https://doi.org/10.1016/j.bone.2020.115542)
- [3] Chen SD, Sari CR, Gao H, Lei Y, Segers P, De Beule M, et al. Mechanical and morphometric study of mitral valve chordae tendineae and related papillary muscle. *J Mech Behav Biomed Mater*. 2020;111:104011. DOI: [10.1016/j.jmbbm.2020.104011](https://doi.org/10.1016/j.jmbbm.2020.104011)
- [4] Pawade T, Sheth T, Guzzetti E, Dweck MR, Clavel MA. Why and how to measure aortic valve calcification in patients with aortic stenosis. *JACC Cardiovasc Imaging*. 2019;12(9):1835–48. DOI: [10.1016/j.jcmg.2019.01.045](https://doi.org/10.1016/j.jcmg.2019.01.045)
- [5] Zebhi B, Lazkani M, Bark D Jr. Calcific aortic stenosis – a review on acquired mechanisms of the disease and treatments. *Front Cardiovasc Med*. 2021;8:734175. DOI: [10.3389/fcvm.2021.734175](https://doi.org/10.3389/fcvm.2021.734175)
- [6] Kraler S, Blaser MC, Aikawa E, Camici GG, Lüscher TF. Calcific aortic valve disease: From molecular and cellular mechanisms to medical therapy. *Eur Heart J*. 2022;43(7):683–97. DOI: [10.1093/eurheartj/ehab757](https://doi.org/10.1093/eurheartj/ehab757)
- [7] Chernykh M, Berezovskyi A, Shamrai V, Postolovskiy L. Clinical and morphological changes of the cardiovascular system in patients with cardioneurosis (neurocirculatory dystonia). *Rep Vinnytsia Natl Med Univ*. 2019;23(3):515–21. DOI: [10.31393/reports-vnmedical-2019-23\(3\)-29](https://doi.org/10.31393/reports-vnmedical-2019-23(3)-29)
- [8] Panchenko Yu, Kovalchuk N. Congenital heart defect and dyslipidemia as risk factors for central retinal artery and branch occlusion [Internet]. In: Rykov S, editor. “Vision for Our Children 2022”. Scientific and Practical Conference of Ukrainian Pediatric Ophthalmologists and Optometrists with International Participation; 2022; Kyiv. Kyiv, UA: Department of Ophthalmology, Shupyk National Healthcare University of Ukraine; 2022. P. 36–37. [cited 2024 Jan 19]. Available from: <http://ir.nuozu.edu.ua:8080/handle/lib/4415>
- [9] Sanchis-Gomar F, Ozemek C, Arena R, Lavie CJ. Another big win for cardiorespiratory fitness now in aortic valve disease. *Eur J Cardiothorac Surg*. 2023;64(5):ezad353. DOI: [10.1093/ejcts/ezad353](https://doi.org/10.1093/ejcts/ezad353)
- [10] Pang K, Wang J, Zhang T, Wu J, Gao Y, Liang Y, et al. Undifferentiated chordae tendineae of the mitral valve: Large cohort study of a rare mitral malformation. *Front Cardiovasc Med*. 2021;8:695536. DOI: [10.3389/fcvm.2021.695536](https://doi.org/10.3389/fcvm.2021.695536)
- [11] Marushko T. [Acute rheumatic fever and chronic rheumatic heart disease](#). *Health Ukraine*. 2020;5(56):32–35.
- [12] Karavanska I. [Infective endocarditis in general practice: Clinical features and diagnosis](#). *Health of Ukraine of the 21st Century*. 2023; 20(557):29,35.
- [13] Kulinichenko V, Mishalov V, Chaikovskiy Yu. Compliance with ethical and legal norms and requirements for conducting scientific morphological research: Methodological recommendations. Kyiv: Bogomolets National Medical University Publishing House; 2007. 29 p.
- [14] Zerbino D, Amosova K, Fedorov Yu, Aksenova O. [Calcific valvular heart disease: Results of pathomorphological study and modern view on morphogenesis](#). *Ukr Med J*. 2002; 3(29):101–4.
- [15] Taylor CR. [Immunomicroscopy: A diagnostic tool for the surgical pathologist](#). Philadelphia: W B Saunders Co; 1986. 452 p.
- [16] Ihnatko O, Holovatskyi A. [Prevalence and significance of bicuspid aortic valve in the pathogenesis of heart diseases](#). *Globalization of Scientific Knowledge: International Cooperation and Integration of Sciences: Proceedings of the III International Student Scientific Conference; 2022; Dnipro*. Vinnytsia, UA: NGO “European Scientific Platform”; 2022. P. 230–31.
- [17] Vitovskiy R, Isaienko V, Vitovskiy A, Satmari O, Yakovenko I, Volkova N. A Case of an unusual clinical course of mitral stenosis. *Ukrainian J Cardiovasc Surg*. 2023;31(2):73–77. DOI: [10.30702/ujcvs/23.31\(02\)/VI017-7377](https://doi.org/10.30702/ujcvs/23.31(02)/VI017-7377)
- [18] Kryvenko V, Kolesnyk M, Kachan I, Borodavko O, Pakhomova S, Fedorova O, Nepriadkina I. Instrumental diagnostics in cardiology: A textbook for doctors, general practitioners, family doctors, physicians of therapeutic orientation, as well as for interns in the specialty “General practice – family medicine” and “Internal diseases”: In 2 parts. Part 2. Zaporizhzhia: Zaporizhzhia State Medical and Pharmaceutical University; 2020. 114 p.
- [19] Fedonyuk LY, Malik YY, Penteleychuk NP, Shtefanets TO. [Reorganization of the endothelium of valvular apparatus of the heart at the infective endocarditis](#). *Morphologia*. 2009;3(1):66–70.
- [20] Chopiak V, Potomkyna H, Valchuk I. [Endothelial cell: Physiology and pathology](#). *Ukr Med J Heart Vessels*. 2004;1(5):105–9.
- [21] Fedoniuk L, Zakharova V, Krykunov O, Boiko M. [Morphological characteristic of the human heart valves in infectious endocarditis](#). *Bukovin Med Herald*. 2004;8(4):83–85.
- [22] Kamenshchuk A. Prognosis of valvular fibrosis development in children with bicuspid aortic valve. *East Ukr Med J*. 2019;7(3):276–84. DOI: [10.21272/eumj.2019;7\(3\):276-284](https://doi.org/10.21272/eumj.2019;7(3):276-284)
- [23] Courtney WA, Schultz CJ, Hillis GS. Aortic valve calcification and outcomes in severe aortic stenosis. *Heart*. 2023;109(19):1426–28. DOI: [10.1136/heartjnl-2023-322771](https://doi.org/10.1136/heartjnl-2023-322771)
- [24] Abdul-Rahman T, Lizano-Jubert I, Garg N, Talukder S, Perez Lopez P, Awuah WA, et al. The common pathobiology between coronary artery disease and calcific aortic stenosis: Evidence and clinical implications. *Prog Cardiovasc Dis*. 2023;79:89–99. DOI: [10.1016/j.pcad.2023.06.002](https://doi.org/10.1016/j.pcad.2023.06.002)
- [25] Ross CJ, Zheng J, Ma L, Wu Y, Lee CH. Mechanics and microstructure of the atrioventricular heart valve chordae tendineae: A review. *Bioengineering*. 2020;7(1):25. DOI: [10.3390/bioengineering7010025](https://doi.org/10.3390/bioengineering7010025)

- [26] Trembovetska O, Pantas O, Kravchenko V, Kravchenko I, Osadovska I. Surgical treatment of patients with a bicuspid aortic valve and concomitant expansion of the ascending aorta. *Ukr J Cardiovasc Surg.* 2023;31(1):53–59. DOI: [10.30702/ujcvcs/23.31\(01\)/TP003-5359](https://doi.org/10.30702/ujcvcs/23.31(01)/TP003-5359)
- [27] Gumpangseth T, Lekawanvijit S, Mahakkanukrauh P. Histological assessment of human heart valves and its relationship with age. *Anat Cell Biol.* 2020;53(3):261–71. DOI: [10.5115/acb.20.093](https://doi.org/10.5115/acb.20.093)
- [28] Papuha O. [Development of dermal skin equivalents using human cells and new biomaterials for the treatment of massive burns](#) [dissertation]. Kyiv, UA; Institute of Molecular Biology and Genetics of the National Academy of Sciences of Ukraine; 2021.167 p.
- [29] Sugiura M, Hiraoka K, Okawa S. A histological study on the conduction system in 16 cases of right bundle branch block associated with right axis deviation. *Jpn Heart J.* 1974;15(2):113–25. DOI: [10.1536/jhj.15.113](https://doi.org/10.1536/jhj.15.113)
- [30] Momberger TS, Levick JR, Mason RM. Hyaluronan secretion by synoviocytes is mechanosensitive. *Matrix Biol.* 2005;24(8):510–19. DOI: [10.1016/j.matbio.2005.08.006](https://doi.org/10.1016/j.matbio.2005.08.006)
- [31] Aikawa E, Hutcheson JD. The developmental origin of calcific aortic stenosis. *N Engl J Med.* 2022 Apr 7;386(14):1372–74. DOI: [10.1056/NEJMcibr2200439](https://doi.org/10.1056/NEJMcibr2200439)
- [32] Shaposhnyk O, Prykhodko N, Savchenko L, Shevchenko T, Sorokina S, Yakymyshyna L, Kudria I. Clinical and diagnostic aspects of managing patients with valvular heart disease. *World Med Biol.* 2022;2(80):178–83. DOI: [10.26724/2079-8334-2022-2-80-178-183](https://doi.org/10.26724/2079-8334-2022-2-80-178-183)
- [33] Stone PH. Management of the patient with asymptomatic aortic stenosis. *J Card Surg.* 1994;9(2 Suppl):139–44. DOI: [10.1111/j.1540-8191.1994.tb00913.x](https://doi.org/10.1111/j.1540-8191.1994.tb00913.x)

Морфологічні зміни структурних компонентів клапанів серця людини, які пов'язані з хронічною гемодинамічною травмою

Лариса Федонюк

Доктор медичних наук, професор
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0003-4910-6888>

Олена Руденко

Кандидат медичних наук, провідний науковий співробітник
Національний інститут серцево-судинної хірургії імені М. М. Амосова
02000, вул. Миколи Амосова, 6, м. Київ, Україна
<https://orcid.org/0000-0003-3640-566X>

Олена Ружицька

Кандидат біологічних наук, асистент
Тернопільський національний медичний університет імені І. Я. Горбачевського
Міністерства охорони здоров'я України
46001, майдан Волі, 1, м. Тернопіль, Україна
<https://orcid.org/0000-0001-6846-888X>

Павло Жученко

Кандидат медичних наук, доцент
Вінницький національний медичний університет імені М.І. Пирогова
21018, вул. Пирогова, 56, м. Вінниця, Україна
<https://orcid.org/0000-0002-3448-1792>

Анотація. Архітектоніка клапанів серця оптимально адаптована до їх фізіологічної функції – рівномірному розподілу потоків крові в камерах серця, тому навіть невеликі зміни структурних компонентів клапанів, які спочатку є функціонально компенсованими, відіграють значну роль у розвитку вади серця на більш пізніх етапах життя хворого. Метою дослідження було з'ясувати вплив хронічної гемодинамічної травми на структурну реорганізацію клапанів серця людини. Досліджено 1377 клапанів серця людини, які отримані під час операції протезування клапанів у Національному інституті серцево-судинної хірургії ім. М. М. Амосова з 2010 по 2022 рік. Під час дослідження визначався повний набір варіантів макро- та мікроскопічних змін морфологічних структур, які характерні для ревматичної хвороби серця, інфекційного ендокардиту, диспластичних і деструктивних змін клапанів серця. Сукупність всіх морфологічних ознак були об'єднані в алгоритм «Морфологічні прояви набутих вад серця різного генезу». Встановлено, що зміна архітектоніки мітрального клапана призводять до

тран-сформації його структурних компонентів, що викликає порушення функціональних можливостей клапана. Було досліджено, що стійкі зміни, які пов'язані з хронічною гемодинамічною травмою, зменшують механічну міцність клапана, незважаючи на компенсаторний механізм гіперплазії субендотеліальних гладких м'язових волокон у стулках клапанів серця. У подальшому дані пошкодження можуть, з однієї сторони, поглиблюватися за рахунок фіброзу, жирової дегенерації та кальцинозу, а з іншої – у процес включаються компенсаторні механізми, а саме гіперплазія субендотеліальних м'язових клітин, яка часто формує суцільні пласти, що повинні посилити та укріпити механічну міцність, і тим самим – функціональну компетентність клапанів. Дисплазія мітрального клапана може призвести до розвитку вторинного інфекційного ендокардиту, ревматизму та вади клапана дегенеративного генезу. Алгоритм визначення закономірностей морфологічних змін клапанного апарату серця при різнома-нітних варіантах набутих вад запального та незапального генезів може бути використаний при удосконаленні схем етіопатогенетичного медикаментозного лікування хворих з набутими вадами серця, а також – в якості теоретичної основи для розробки нових видів клапанозберігаючих операцій

Ключові слова: морфологічна перебудова; клапанна система серця; гемодинамічна травма; світлова мікроскопія

ВІСНИК МЕДИЧНИХ І БІОЛОГІЧНИХ ДОСЛІДЖЕНЬ
науково-практичний журнал

Том 6, № 1
2024

Відповідальний редактор:
Т. П'ятковський

Редагування бібліографічних списків:
Т. П'ятковський

Редагування англomовних текстів:
К. Касьянов

Комп'ютерна верстка:
О. Глінченко

Підписано до друку 27.02.2024
Формат 60*84/8
Ум. друк. арк. 10,2
Наклад 100 прим.

Видавництво:
Тернопільський національний медичний університет імені І. Я. Горбачевського
46001, майдан Волі, 1, м. Тернопіль, Україна
Тел.: +380 352 524492
E-mail: info@bibr.com.ua
<https://bibr.com.ua/uk>

BULLETIN OF MEDICAL AND BIOLOGICAL RESEARCH
Scientific-Practical Journal

Volume 6, No. 1
2024

Managing Editor:

T. Pyatkovskyy

Editing bibliographic lists:

T. Pyatkovskyy

Editing English-Language Texts:

K. Kasianov

Desktop publishing:

O. Glinchenko

Signed to the print 27.02.2024

Format 60*84/8

Conventional Printed Sheet 10.2

Circulation 100 copies

Publisher:

I. Horbachevsky Ternopil National Medical University

46001, 1 Maidan Voli, Ternopil, Ukraine

Tel.: +380 352 524492

E-mail: info@bibr.com.ua

<https://bibr.com.ua/en>