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Simulation-Based Training Using the "Sechenov" Virtual Platform in Gastrointestinal Surgery

Yuriy L. Vasil'ev*, Olesya V. Kytko, Marina A. Kinkulkina, Beatrice A. Volel, Tatyana M. Litvinova, Konstantin V. Ivashkin, Elena O. Bakhrushina, Evgeniya I. Voronova, Ekaterina V. Rebrova, Elizaveta N. Kytko, Sergey A. Tregubov, Artem D. Kashtanov, Elena A. Son, Kirill A. Zhandarov, Natalia D. Ivanova, Dmitry S. Leonov, Hadi M.S. Darawsheh, Artem V. Mirontsev, Sergey S. Dydykin

I.M. Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russian Federation

Aim: to evaluate the effectiveness of educational technology using virtual reality in abdominal surgery.
Materials and methods. The study was conducted using the domestic virtual reality platform "Sechenov" and abdominal surgery simulators. When launching the software modules "Operation — Cholecystectomy" and "Operation — Gastric Resection", an anatomical model of a human body with detailed internal organs of the abdominal cavity appears next to the user, and it has an anchor point in the center of the location. The tasks are completed through the assessment of the results of the survey of students using the Likert system, as well as several open clarifying questions. Based on the results of the analysis, two groups were formed: those students who had no experience working with virtual systems and students who had previous experience working in virtual reality simulators, including cases of rehabilitation after injuries.
Results. When analyzing the ergonomics of simulator control depending on the experience of using virtual reality outside of educational purposes, it was not possible to establish statistically significant differences ($p = 0.393$). However, depending on the experience of using virtual simulators for educational purposes, statistically significant differences were established ($p = 0.014$). When comparing data on satisfaction with participation in training depending on the experience of using virtual reality outside of educational purposes, no significant differences were found ($p = 0.875$). When analyzing the educational value of the teaching methodology depending on previous experience using virtual simulators, statistically significant differences were found ($p = 0.023$).
Conclusions. The virtual reality simulator in abdominal surgery provides the opportunity to add new educational scenarios; reduces the fear of mistakes in students; not only allows for training in manipulations but also serves as a teaching aid on the clinical anatomy of the stomach and hepatobiliary complex.
Keywords: abdominal surgery, simulation, virtual environment, education, medicine, ergonomics, motivation
Conflict of interest: the authors declare no conflict of interest.

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Опыт симуляционного образования с применением виртуальной платформы «Сеченов» в хирургии желудочно-кишечного тракта

Ю.Л. Васильев*, О.В. Кытько, М.А. Кинкулькина, Б.А. Волель, Т.М. Литвинова, К.В. Ивашкин, Е.О. Бахрушина, Е.И. Воронова, Е.В. Реброва, Е.Н. Кытько, С.А. Трегубов, А.Д. Каштанов, Е.А. Сон, К.А. Жандаров, Н.Д. Иванова, Д.С. Леонов, Х.М.С. Дарауше, А.В. Миронцев, С.С. Дыдыкин

ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет), Москва, Российская Федерация

Цель исследования: оценка эффективности образовательной технологии с применением виртуальной реальности в абдоминальной хирургии.
Материалы и методы. Исследование проведено с использованием отечественной платформы виртуальной реальности «Сеченов» и симуляторов абдоминальной хирургии. При запуске программных модулей «Операция — Холецистэктомия» и «Операция — Резекция желудка» рядом с пользователем появляется анатомическая модель человека с размещением детализированных внутренних органов брюшной полости, ко-

торая имеет якорную точку в центре локации. Выполнение задач реализовано через оценку результатов анкетирования обучающихся по системе Likert, а также нескольких открытых уточняющих вопросов. По итогам анализа были сформированы две группы: обучающиеся, у которых не было опыта работы с виртуальными системами, и обучающиеся, имевшие ранее опыт работы в симуляторах виртуальной реальности, в том числе для реабилитации после полученных травм.
Результаты. При анализе эргономики управления симулятором в зависимости от опыта использования виртуальной реальности вне учебных целей не было выявлено статистически значимых различий (p = 0,393). Однако были обнаружены статистически значимые различия (p = 0,014) в зависимости от опыта применения виртуальных симуляторов в учебных целях. При сопоставлении данных об удовлетворенности от участия в обучении в зависимости от опыта использования виртуальной реальности вне учебных целей значимых различий не выявлено (p = 0,875). При анализе образовательной ценности методики преподавания в зависимости от предыдущего опыта применения виртуальных симуляторов были выявлены статистически значимые различия (p = 0,023).
Выводы. Симулятор виртуальной реальности в абдоминальной хирургии предоставляет возможность добавления новых образовательных сценариев; снижает страх ошибки у студентов; а также он не только позволяет обучить манипуляциям, но и служит обучающим пособием по клинической анатомии желудка и гепатобилиарного комплекса.
Ключевые слова: абдоминальная хирургия, симулятор, виртуальная среда, образование, медицина, эргономика, мотивация
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

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Introduction

Since the mid-20th century, technology has developed rapidly, which has led to an increased need for qualified specialists in various fields of science. In response to this, educational requirements have changed. The modern approach to learning involves an interdisciplinary and comprehensive approach to solving problems. Learning is project-based, and courses have a practical focus [1].

Virtual reality has become an integral part of the educational process, and the COVID-19 pandemic has accelerated its development. Future doctors, especially those who have chosen the surgical direction of training, have the opportunity to immerse themselves in an interactive environment where they can develop their skills and even perform virtual surgeries [2, 3].

One of the main advantages of virtual reality in training future surgeons is the ability to create realistic environments where users can practice their manual skills without harming animals or real patients [4]. Any virtual manual process created with the help of special programs can be reproduced and used an unlimited number of times without significant expenditure of time and money [5]. While virtual surgical simulations do not replace real-life procedures, they provide detailed preparation for actual surgical interventions [6].

This approach to education is also highly cost-effective. In virtual reality, you can create a variety of situational tasks of varying complexity, especially for such a complex part of the body as the abdominal cavity. It is also possible to upload explanatory photos and videos for self-training. And finally, at the adaptation and training stage, there is no need to spend expensive phantom parts [7, 8]. This thesis is supported by the results of the study by G. Ntakakis et al. (2023), which emphasizes that the benefit lies in the minimal material and technical costs [9].

Simulation-based education (SBE) serves as an effective preparatory tool, promoting the development of dissection skills and enhancing knowledge of clinical anatomy [10].

Students and teachers are presented with broad horizons for creative use of augmented and virtual reality, which in turn contributes to improving the quality of education. However, as experience accumulates in the practical use of virtual reality in the educational process, a number of questions arise [3].

The literature review for the query "VR education, surgery" in the PubMed database covers the period from 1993 to 2024 and includes 1302 sources (Fig. 1).

If we narrow the query to the topic of virtual technologies in abdominal surgery, we find 36 sources covering the period from 1998 to 2024.

In one of the first studies devoted to virtual reality in abdominal surgery, M. Bro-Nielsen et al. (1998) demonstrated the effectiveness

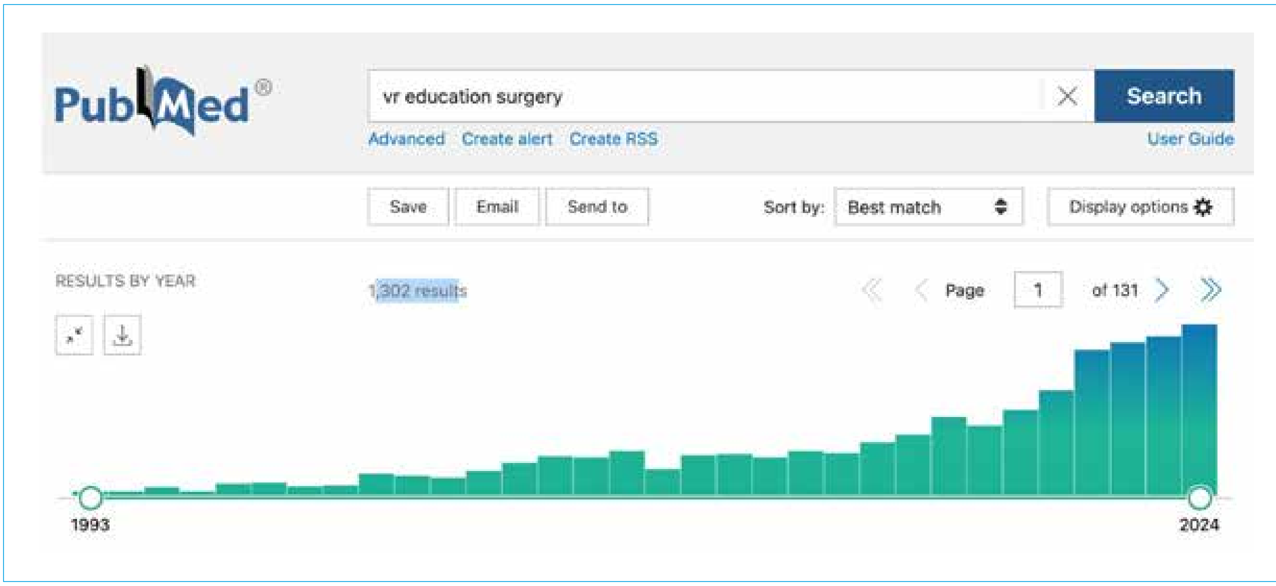

Figure 1. The time frame covering the field of virtual education in surgery

Рисунок 1. Временной диапазон, охватывающий сферу виртуального образования в области хирургии

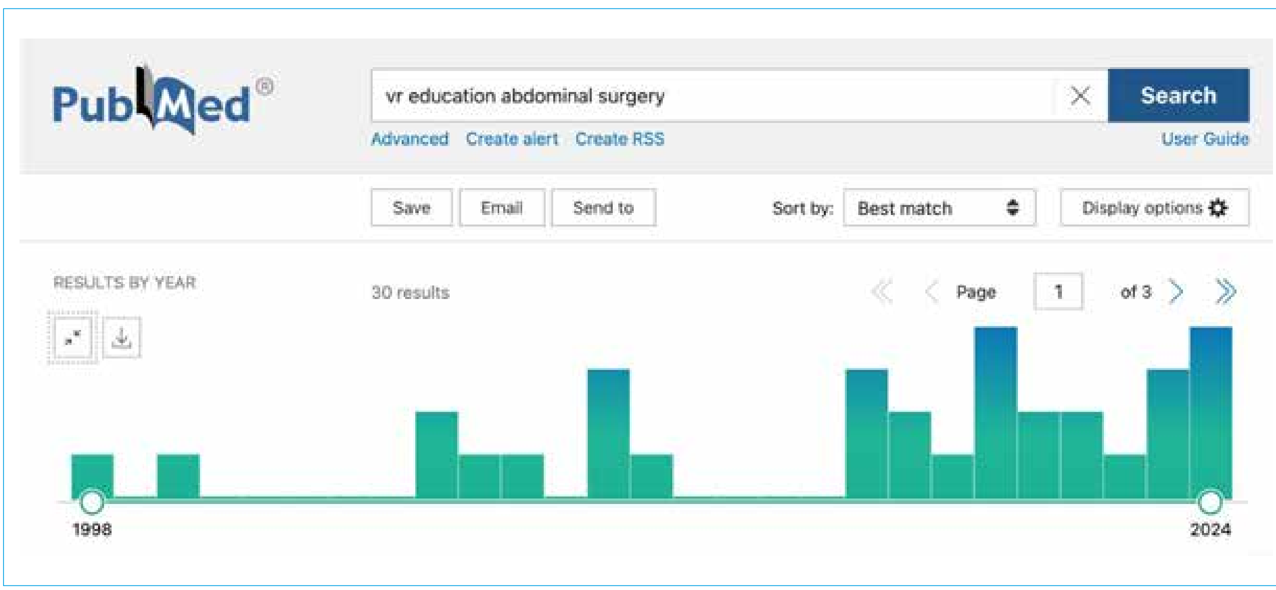

Figure 2. Time coverage of virtual education topics in abdominal surgery

Рисунок 2. Временной диапазон, охватывающий сферу виртуального образования в абдоминальной хирургии

of combining different types of reality, in which physical feedback dependent on the density of simulated tissues is combined with a highly realistic virtual model [11]. Today, this training strategy is reflected in simulators that vary in level of realism and complexity, suitable for training entry-level specialists (Fig. 2).

It is obvious that literary sources were distributed unevenly in different years. Perhaps this is due to the peculiarities of the introduction of technologies into the educational process. Recent studies confirm that the use of immersive virtual reality as a tool in Abdominal Surgery training programs increases student motivation, reduces the time required to master the real technique, and provides economic benefits due to savings on pre-training simulators [12]. This is supported by a study conducted by G. Sankaranarayanan et al. (2021). In their work, they examined how effectively VR technologies can be used for colorectal surgery training [13].

The aim of the study: to evaluate the effectiveness of educational technology using virtual reality in abdominal surgery.

Null hypothesis

The educational strategy involving virtual reality surgical simulators for the integrated topic of 'Abdominal Surgery,' without haptic feedback, is beneficial for learners, and the ergonomic principles of simulator operation depend on prior experience.

Materials and methods

To determine the sample size, it is necessary to take into account the total number of second-year students of the N.V. Sklifosovsky Institute of Clinical Medicine at Sechenov University, which is 2,000 people. The sample should include 322 respondents. The calculation was made using the formula:

$$Ss = \frac{Z^2 \cdot p \cdot (1 - p)}{C^2},$$

where: Ss — the required sample size; Z — the Z-factor (1.96 for a 95% confidence interval); p — the percentage of respondents or responses of interest, in decimal form (0.5 by default); C — the confidence interval (5 %).

The study was conducted using the domestic virtual reality platform "Sechenov" and abdominal surgery simulators. A special feature of these simulators is their operation without tactile feedback. The student's task is to consistently and correctly perform the stages of the operation using surgical instruments. Successful completion of each stage opens access to the next educational module.

The software modules "Operation — Cholecystectomy" and "Operation — Gastrectomy" are based on the core environment of the training platform "AR/VR University", which represents a conceptual medical office of the future. When these modules are launched, an anatomical model of a human with detailed internal organs of the abdominal cavity appears next to the user, which has an anchor point in the center of the location. The model is placed horizontally and is located on the surface of the operating table [14, 15]. The programs operate in two modes: demonstration and practical.

To ensure stable operation, a Learning Management System (LMS) was developed, performing the following functions:

1. Integration with the "AR/VR University" platform;
2. Protection against unauthorized access and copying;
3. Providing students with personalized learning pathways on the "AR/VR University" platform;
4. Facilitating data exchange between the LMS and the "Electronic Dean's Office" subsystem;
5. Maintaining individual statistics of successes and challenges during simulation-based training sessions.

This technology represents the third stage of a multi-step educational trajectory implemented by the Department of Operative Surgery and Topographic Anatomy of the N.V. Sklifosovsky Institute of Clinical Medicine at Sechenov University. The program is aimed at practical training of students and includes several stages: Stage 1 — theoretical training according to the module; Stage 2 — getting to know safety rules and mastering basic manual skills, as well as working with tools; Stage 3 — classes on virtual simulators; Stage 4 — practical classes on biological and anatomical material.

As part of the abdominal surgery training, students have the opportunity to use two simulators: one for performing gastrectomy and one for performing cholecystectomy (Fig. 3).

To solve the problems, a survey was conducted among the students using the Likert system, and several additional questions were also asked. Based on the results of the data analysis, two groups were identified:

1) students who had not previously encountered virtual systems;

2) students who already had experience working with virtual reality simulators, including for rehabilitation after injuries.

The following questions were posed anonymously:

1. Please indicate your gender.
2. Please indicate your age.
3. How many hours per week do you spend on non-academic computer activities?
4. Do you have any health limitations that might prevent you from using virtual simulators?

An important condition for participation was the consent of the students, the absence of claustrophobia, visual impairment, vestibular apparatus and cardiovascular system. Before each use, each virtual helmet was hygienically treated. The students also used disposable face masks.

Next, questions were asked using the Likert scale, in which the respondent assessed his experience in the field of using virtual reality tools using the following parameters and categories:

1. Ergonomics of simulator control:

Categories:

- experience in using virtual medical simulators;
- experience using virtual reality outside of educational purposes.

2. Satisfaction with participation in training:

Categories:

- experience in using virtual medical simulators;

Figure 3. Group training in cholecystectomy on the simulator in the demonstration mode

Рисунок 3. Групповое обучение холецистэктомии на симуляторе в демонстрационном режиме

• experience using virtual reality outside of educational purposes.

3. Educational value of teaching methods:

Categories:

• no experience using virtual reality for educational purposes;

• user experience — VR class at the Department of Operative Surgery and Topographic Anatomy.

4. Usefulness of the teaching methodology in terms of acquiring knowledge in the future:

Categories:

• no experience using virtual reality for educational purposes;

• user experience — VR class at the Department of Operative Surgery and Topographic Anatomy.

5. Age:

Categories:

• usefulness of the teaching methodology in terms of acquiring knowledge in the future;

• educational value of teaching methods.

The following response options were offered: “very poorly”, “poorly”, “neutral”, “well”, and “very well”.

The results of the study were processed in IBM SPSS Statistics 26 [rus] (“SPSS: An IBM Company”, USA) and Microsoft Excel 2016 (Microsoft Corp., USA). Quantitative variables were assessed for conformity to a normal distribution using the Kolmogorov — Smirnov test. For variables that did not follow a normal distribution, the data were described using the median (*Me*) and the interquartile range (*Q*1; *Q*3). Categorical data were presented as absolute values and percentages. Comparisons between two groups for quantitative variables that did not follow a normal distribution were performed using the Mann — Whitney *U* test. Comparisons among three or more groups for non-normally distributed quantitative variables were conducted using the Kruskal — Wallis test, with post-hoc comparisons carried out using Dunn’s test with Holm’s correction. A predictive model characterizing the dependence of a quantitative variable on various factors was developed using linear regression analysis. To evaluate the diagnostic significance of quantitative variables in predicting a specific outcome, ROC curve analysis was applied. The cut-off value for a quantitative variable was determined at the point of the highest Youden index. Differences were considered statistically significant at $p < 0.05$.

Results

In fact, the comparison was carried out in two categories, where some of the students had not previously encountered working on virtual simulators, while others had similar experience as part of classes in the virtual reality laboratory organized at the Department of Operative Surgery and Topographic Anatomy of the N.V. Sklifosovsky Institute of Clinical Medicine of Sechenov University.

We evaluated the ergonomics of operating a virtual reality simulator based on prior experience using virtual reality for non-academic purposes (Table 1).

In the analysis of simulator ergonomics based on prior experience with virtual reality for non-academic purposes, no statistically significant differences were identified ($p = 0.393$).

An additional analysis was conducted on the ergonomics of operating the simulator based on prior experience with virtual simulators for academic purposes (Fig. 4).

As a result of comparing simulator ergonomics based on prior experience with virtual simulators for academic purposes, statistically significant differences were identified ($p = 0.014$) (Fig. 5, 6).

To evaluate the quality of immersive learning, we also assessed students' satisfaction with participating in virtual reality simulator training. This evaluation was conducted based on their prior experience using immersive virtual reality applications and therapeutic programs (Table 3). When comparing the obtained data, it was not possible to identify significant differences ($p = 0.875$) (Fig. 7).

Medical education is primarily grounded in practical training and the accumulation of experience and skills. In this context, analyzing the educational value of the teaching methodology based on prior experience with virtual simulators was of particular interest to us (Table 4).

Based on the data obtained from the analysis of the educational value of the teaching methodology in relation to prior experience with virtual simulators, statistically significant differences were identified ($p = 0.023$).

An analysis was also conducted on the usefulness of the teaching methodology for acquiring knowledge in the future, based on prior experience with virtual simulators (Table 5).

Table 1. Analysis of the ergonomics of the simulator control depending on the experience of using virtual reality outside of educational purposes

Таблица 1. Анализ эргономики управления симулятора в зависимости от опыта использования виртуальной реальности вне учебных целей

Categories ***Категории***	**Number of people** ***Количество человек***	**Ergonomics of simulator control** ***Эргономика управления симулятором*** ***Me* (*Q*1; *Q*3)***
No experience using virtual reality *Нет опыта использования виртуальной реальности*	190	4.00 (3.00; 4.00)
User experience — gaming applications *Опыт использования — игровые приложения*	108	4.00 (3.00; 4.00)
User experience — physiotherapy after injury *Опыт использования — лечебная физкультура после травмы*	24	4.00 (3.50; 5.00)

Note: ** — p = 0.393 (Kruskal — Wallis test).*

Примечание: ** — p = 0,393 (критерий Краскела — Уоллиса).*

Table 2. Analysis of the ergonomics of the simulator control depending on the experience of using virtual medical simulators

Таблица 2. Анализ эргономики управления симулятором в зависимости от опыта использования виртуальных медицинских симуляторов

Categories ***Категории***	**Number of people** ***Количество человек***	**Ergonomics of simulator control** ***Эргономика управления симулятором*** ***Me* (*Q*1; *Q*3)***
No experience using virtual reality for educational purposes *Нет опыта использования виртуальной реальности в учебных целях*	161	3.50 (3.00; 4.00)
User experience — VR class at the Department of Operative Surgery and Topographic Anatomy *Опыт использования — VR-класс на кафедре оперативной хирургии и топографической анатомии*	161	4.00 (3.00; 4.75)

Note: ** — p = 0.014 (Mann — Whitney test), differences are statistically significant (p < 0.05).*

Примечание: ** — p = 0,014 (критерий Манна — Уитни), различия показателей статистически значимы (p < 0,05).*

Figure 4. Work in a virtual operating room during the first stage of gastric resection surgery

Рисунок 4. Работа в виртуальной операционной при выполнении первого этапа вмешательства по поводу резекции желудка

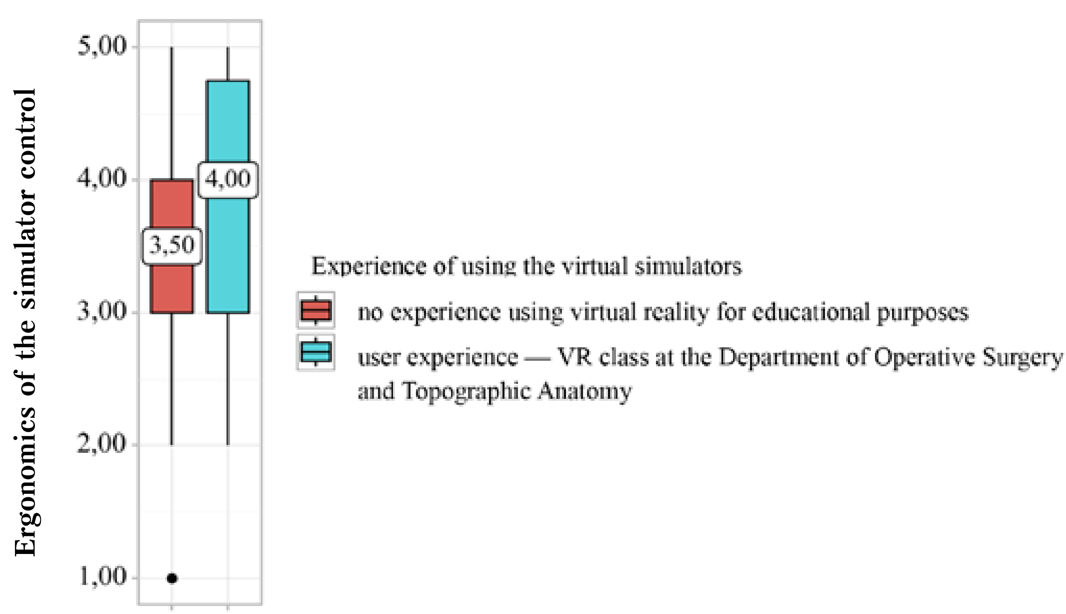

Figure 5. Analysis of the ergonomics of the simulator control depending on the experience of using the virtual medical simulators

Рисунок 5. Анализ эргономики управления симулятором в зависимости от опыта использования виртуальных медицинских симуляторов

Figure 6. Ergonomics of a nonlinear virtual simulator in the “Sechenov” educational system

Рисунок 6. Эргономика нелинейного виртуального симулятора в образовательной системе «Сеченов»

Table 3. Analysis of satisfaction from participation in training depending on the experience of using virtual reality outside of educational purposes

Таблица 3. Анализ удовлетворенности от участия в обучения в зависимости от опыта использования виртуальной реальности вне учебных целей

Categories ***Категории***	**Number of people** ***Количество человек***	**Satisfaction with participation in training** ***Удовлетворенность от участия в обучении Me (Q1; Q3)****
No experience using virtual reality *Нет опыта использования виртуальной реальности*	161	4.00 (4.00; 4.00)
User experience — gaming applications *Опыт использования — игровые приложения*	142	4.00 (4.00; 5.00)
User experience — physiotherapy after injury *Опыт использования — лечебная физкультура после травмы*	19	4.00 (3.50; 5.00)

Note: ** — p = 0.875 (Kruskal — Wallis test).*
Примечание: ** — p = 0,875 (критерий Краскела — Уоллиса).*

As a result of analyzing the usefulness of the teaching methodology for acquiring knowledge in the future based on prior experience with virtual simulators, significant differences were identified ($p = 0.031$).

A correlation analysis was conducted to assess the relationship between the age of students and the usefulness of the teaching methodology for acquiring knowledge in the future (Table 6).

When assessing the relationship between the usefulness of the teaching methodology for acquiring knowledge in the future and age, no significant correlation was found. The observed relationship between the usefulness of the teaching methodology for acquiring knowledge in the future and age is described by the equation of simple linear regression:

$$Y = 0.047 \times X + 3.161,$$

where: Y — usefulness of the teaching methodology for acquiring knowledge in the future; X — age.

An increase in age by 1 unit is expected to result in an increase in the usefulness of the teaching methodology for acquiring knowledge in the future by 0.047. The model explains 0.3 % of the observed

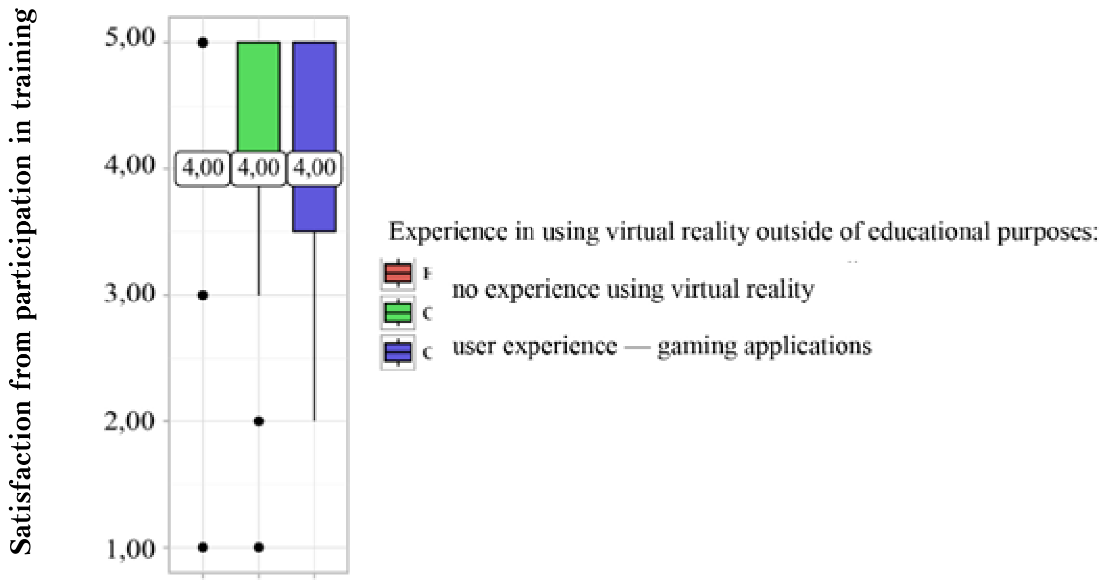

Figure 7. Analysis of satisfaction from participation in training depending on the experience of using virtual reality outside of educational purposes

Рисунок 7. Анализ удовлетворенности от участия в обучения в зависимости от опыта использования виртуальной реальности вне учебных целей

Table 4. Analysis of the educational value of the teaching methodology depending on the experience of using a virtual medical simulator

Таблица 4. Анализ образовательной ценности методики преподавания в зависимости от опыта использования виртуального медицинского симулятора

Categories ***Категории***	**Number of people** ***Количество человек***	**Educational value of teaching methods** ***Образовательная ценность методики преподавания*** ***Me* (Q1; Q3)***
No experience using virtual reality for educational purposes *Нет опыта использования виртуальной реальности в учебных целях*	161	4.00 (3.00; 4.75)
User experience — VR class at the Department of Operative Surgery and Topographic Anatomy *Опыт использования — VR-класс на кафедре оперативной хирургии и топографической анатомии*	161	4.00 (4.00; 5.00)

Note: ** — $p = 0.023$ (Mann — Whitney test). differences are statistically significant ($p < 0.05$).*

variance in the usefulness of the teaching methodology for acquiring knowledge in the future.

A correlation analysis was conducted to assess the relationship between age and expectations regarding the teaching methodology (Table 7).

When assessing the relationship between the educational value of the teaching methodology and age, no significant correlation was found. The observed relationship between the educational value of the teaching methodology and age is described by the equation of simple linear regression:

$$Y = 0.036 \times X + 3.313,$$

where: Y — educational value of the teaching methodology; X — age.

An increase in age by 1 unit is expected to result in an increase in the educational value of the teaching methodology by 0.036. The model explains 0.2 % of the observed variance in the educational value of the teaching methodology.

Table 5. Analysis of the usefulness of the teaching methodology in terms of acquiring knowledge in the future. depending on previous experience in using virtual medical simulators

Таблица 5. Анализ полезности методики преподавания с точки зрения овладения знания в будущем в зависимости от предыдущего опыта использования виртуальных медицинских симуляторов

Categories ***Категории***	**Number of people** ***Количество человек***	**The usefulness of the teaching methodology in terms of future knowledge acquisition** ***Полезность методики преподавания с точки зрения овладения знаниями в будущем*** ***Me (Q1; Q3)****
No experience using virtual reality for educational purposes *Нет опыта использования виртуальной реальности в учебных целях*	161	4.00 (3.00; 5.00)
User experience — VR class at the Department of Operative Surgery and Topographic Anatomy *Опыт использования — VR-класс на кафедре оперативной хирургии и топографической анатомии*	161	4.00 (4.00; 5.00)

Note: ** — p = 0.031 (Mann — Whitney test). differences are statistically significant (p < 0.05).*
Примечание: ** — p = 0.031 (критерий Манна — Уитни). различия показателей статистически значимы (p < 0.05).*

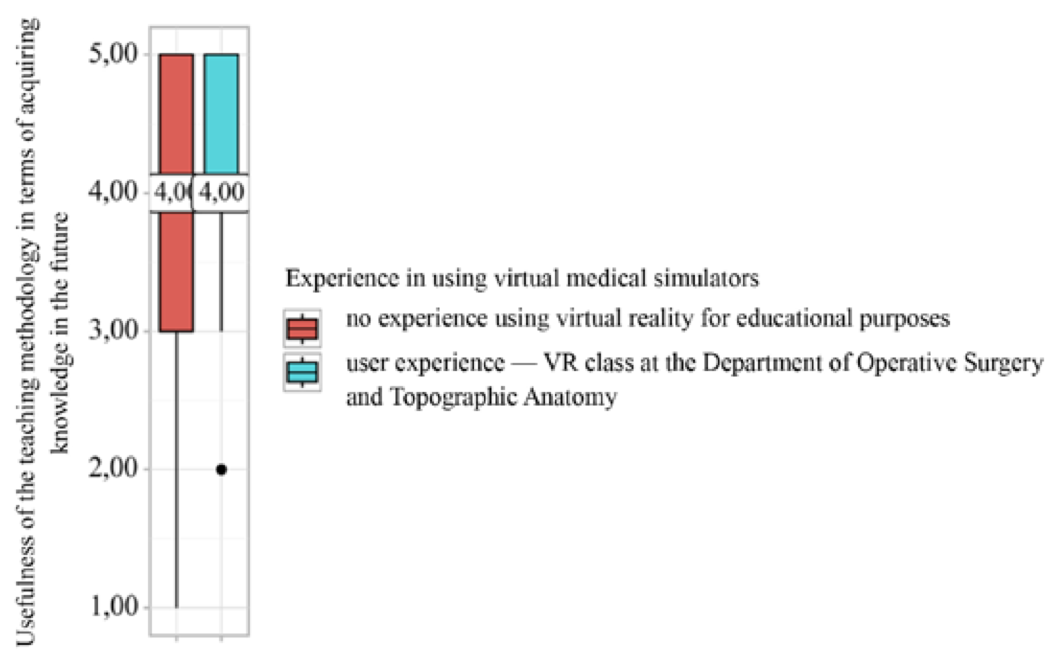

Figure 8. Analysis of the usefulness of the teaching methodology in terms of acquiring knowledge in the future, depending on previous experience in using virtual medical simulators

Рисунок 8. Анализ полезности методики преподавания с точки зрения овладения знаниями в будущем в зависимости от предыдущего опыта использования виртуальных медицинских симуляторов

Discussion

This study examined how virtual reality experiences impact immersion learning outcomes. The integration of technology into education opens up new and more effective learning opportunities. Research shows that virtual reality can improve knowledge of anatomy and spatial perception.

The first surgical simulators began to appear in the late 20th century. The main ideas at that time were the assumption that the surgeon of the future would be able to study anatomy in a new way and repeatedly practice surgical procedures until they were flawless before performing surgery on real patients

Table 6. Results of the correlation analysis of the relationship between age and the usefulness of teaching methods in terms of acquiring knowledge in the future
Таблица 6. Результаты корреляционного анализа взаимосвязи возраста и полезности методики преподавания с точки зрения овладения знаниями в будущем

Parameter ***Показатель***	**Characteristics of the correlation relationship** ***Характеристика корреляционной связи***		
	p	**Chaddock's tightness of correlation scale** ***Теснота связи по шкале Чеддока***	***p***
Age — Usefulness of the teaching method in terms of future acquisition of knowledge *Возраст — Полезность методики преподавания с точки зрения овладения знаниями в будущем*	0.057	No correlation / *Нет связи*	0.503

Table 7. Results of the correlation analysis of the relationship between age and the educational value of teaching methods
Таблица 7. Результаты корреляционного анализа взаимосвязи возраста и образовательной ценности методики преподавания

Parameter ***Показатель***	**Characteristics of the correlation relationship** ***Характеристика корреляционной связи***		
	p	**Chaddock's tightness of correlation scale** ***Теснота связи по шкале Чеддока***	***p***
Age — Educational value of teaching methods *Возраст — Образовательная ценность методики преподавания*	0.029	No correlation / *Нет связи*	0.730

[16, 17]. Our studies have largely confirmed this statement, especially given the current difficulties with access to anatomical material traditionally used for surgical training [18]: difficulties in accessing cadavers and their shortage for the broad educational process force us to look for alternative solutions. One of these solutions was the use of virtual systems. They offer the principle of zero costs and multiple attempts, which is especially relevant given the uncertain outcome of the first attempt at independent work with real anatomical material.

We can draw some parallels with the past, when during the COVID-19 pandemic, students did not have access to cadavers. Since the 17th century, this was the main way to study anatomy [19]. Unfortunately, the pandemic has led to two inevitable consequences: potential problems in the education system and students' uncertainty about the future of their professions [20]. However, our study showed that the transition from an extracurricular format to an educational process in a virtual reality environment does not cause stress for students. This may be due to the universal rules of interaction within the simulator, as well as the general order of control and response to non-gravitational feedback in the form of manipulator vibrations or audio signals.

Our study of simulator ergonomics showed that regardless of previous experience using VR outside of educational purposes, students found the environment equally comfortable. This is consistent with earlier work [21] that used virtual reality as a communication tool. The illusion of absence of intermediaries and a sense of community, as well as familiar navigation, increase engagement in the process.

H.G. Kenngott et al. (2024) conducted a study of a surgical simulator for the treatment of hepatobiliary pathology. They noted that the majority of users (89.9 %) highly rated the ease of use of this simulator. They saw particularly high potential in teaching students (87.3 %) and residents (84.6 %) [22]. These results confirm our point of view that such a teaching method may be useful for future specialization.

Overall, a review of literature evaluating the effectiveness of surgical simulators for abdominal surgery training suggests that our findings are substantiated. The results show that the use of simulators promotes faster engagement in the educational process and helps to avoid stress associated with the need to adapt to new working conditions [23, 24]. In addition, simulation training promotes a more successful transition to performing real operations [25].

One of the key benefits of training in gastroenterology and abdominal surgery is the opportunity to study 'endoscopically', which creates the participation effect. In the virtual environment, changes can be observed in accordance with the movement of instruments during diagnostic and surgical procedures. These observations can be supplemented by lecture material or comments from the teacher.

However, in addition to the obvious advantages, it is also necessary to note some limitations associated with the introduction of technology into mass education. Some students may experience health problems when using virtual reality: nausea, dizziness and pain in the cervical region. In addition, the graphic and visual models must be carefully detailed to ensure that they are accurate and realistic. It is also necessary to ensure that virtual and physical reality are accurately combined. It is also worth noting that there is an insufficient amount of research and testing from the point of view of evidence-based medicine, which does not allow us to draw final conclusions about the safety and effectiveness of the technology for widespread use in education.

In the modern world, technological innovations have changed the approach to medical education, posing new challenges. The inclusion of research skills in the educational process contributes to the qualitative transformation of medical education and the training of specialists who are able to compete in the labor market and are in demand in a rapidly developing world [26].

It is also worth mentioning the difficulties that virtual reality laboratory organizers face when implementing such technologies. Educational institutions are faced with the need to provide a material base for such laboratories: create virtual classrooms, purchase and configure virtual reality equipment, and train scientific and pedagogical staff [27].

Our previous experience has shown that in groups where three-dimensional anatomical complexes were used during classes, the acquisition of knowledge significantly improved. Students began to participate more actively in the educational process, and their interest in innovative methods of conducting classes increased significantly [28].

In conclusion, it is worth highlighting several key advantages of virtual simulators, both in the field of abdominal surgery and in medicine in general:

- *expansion of educational scenarios and language:* virtual simulators allow the creation of new learning scenarios and language, which opens up new horizons for educational processes;
- *reduced fear of making mistakes:* students can make mistakes without fear of damaging the physical model, which reduces anxiety and promotes greater confidence in performing manipulations;
- *non-linear use of the educational complex:* as we have seen in our study, virtual simulators can be used not only for teaching various manipulations, but also serve as a teaching aid on the clinical anatomy of the stomach and hepatobiliary complex.

Conclusions

The experience of using virtual surgical simulators in other areas of life and the age of students do not influence such factors as the ease of operating the simulator, satisfaction with participation in the educational process, and expectations from the teaching methodology. However, the experience of using virtual reality simulators for educational purposes directly affects the improvement of the effectiveness of training. This technology helps students to learn the material in a three-dimensional environment, which contributes to a better understanding of the discipline and the acquisition of new knowledge.

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Information about the authors

Yuriy L. Vasil'ev* — Dr. Sci. (Med.), Professor of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: vasilev_yu_l@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0003-3541-6068

Сведения об авторах

Васильев Юрий Леонидович* — доктор медицинских наук, профессор кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: vasilev_yu_l@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0003-3541-6068

* Corresponding author / Автор, ответственный за переписку

Olesya V. Kytko — Cand. Sci. (Med.), Associate Professor of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: kytko_o_v@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0001-5472-415X

Кытько Олеся Васильевна — кандидат медицинских наук, доцент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: kytko_o_v@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо 15/13, стр. 1.
ORCID: https://orcid.org/0000-0001-5472-415X

Marina A. Kinkulkina — Dr. Sci. (Med.), Professor, Head of the Department of Psychiatry and Narcology, Director of the Institute of Electronic Medical Education, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: kinkulkina_m_a@staff.sechenov.ru;
119435, Moscow, Pogodinskaya str., 1, build. 1.
ORCID: https://orcid.org/0000-0001-8386-758X

Кинкулькина Марина Аркадьевна — доктор медицинских наук, профессор, заведующий кафедрой психиатрии и наркологии, директор Института электронного медицинского образования, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: kinkulkina_m_a@staff.sechenov.ru;
119435, г. Москва, ул. Погодинская, 1, стр. 1.
ORCID: https://orcid.org/0000-0001-8386-758X

Beatrice A. Volel — Dr. Sci. (Med.), Professor of the Department of Psychiatry and Psychosomatics, Director of the N.V. Sklifosovsky Institute of Clinical Medicine, I.M.Sechenov First Moscow State Medical University (Sechenov University).
Contact information: volel_b_a@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 11, build. 2.
ORCID: https://orcid.org/0000-0003-1667-5355

Волель Беатриса Альбертовна — доктор медицинских наук, профессор кафедры психиатрии и психосоматики, директор Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: volel_b_a@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 11, стр. 2.
ORCID: https://orcid.org/0000-0003-1667-5355

Tatyana M. Litvinova — Cand. Sci. (Pharm.), Docent, Vice-Rector for Academic Affairs, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: litvinova_t_m_1@staff.sechenov.ru;
119435, Moscow, Bolshaya Pirogovskaya str., 2, build. 4.
ORCID: https://orcid.org/0000-0003-0820-0755

Литвинова Татьяна Михайловна — кандидат фармацевтических наук, доцент, проректор по учебной работе, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: litvinova_t_m_1@staff.sechenov.ru;
119435, г. Москва, ул. Большая Пироговская, 2, стр. 4.
ORCID: https://orcid.org/0000-0003-0820-0755

Konstantin V. Ivashkin — Dr. Sci. (Med.), Professor of the Department of Propaedeutics of Internal Diseases, Gastroenterology and Hepatology, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: ivashkin_k_v_1@staff.sechenov.ru;
119435, Moscow, Pogodinskaya str., 1, build. 1.
ORCID: https://orcid.org/0000-0002-5699-541X

Ивашкин Константин Владимирович — доктор медицинских наук, профессор кафедры пропедевтики внутренних болезней, гастроэнтерологии и гепатологии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: ivashkin_k_v_1@staff.sechenov.ru;
119435, г. Москва, ул. Погодинская, 1, стр. 1.
ORCID: https://orcid.org/0000-0002-5699-541X

Elena O. Bakhrushina — Cand. Sci. (Pharm.), Associate Professor of the Department of Pharmaceutical Technology, A.P. Nelubin Institute of Pharmacy, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: bakhrushina_e_o@staff.sechenov.ru;
119571, Moscow, Vernadsky Avenue, 96, build. 1.
ORCID: https://orcid.org/0000-0001-8695-0346

Бахрушина Елена Олеговна — кандидат фармацевтических наук, доцент, доцент кафедры фармацевтической технологии Института фармации им. А.П. Нелюбина, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: bakhrushina_e_o@staff.sechenov.ru;
119571, г. Москва, просп. Вернадского, 96, корп. 1.
ORCID: https://orcid.org/0000-0001-8695-0346

Evgeniya I. Voronova — Cand. Sci. (Med.), Associate Professor of the Department of Psychiatry and Psychosomatics, Deputy Director of the N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).

Воронова Евгения Ивановна — кандидат медицинских наук, доцент кафедры психиатрии и психосоматики, заместитель директора Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).

Contact information: voronova_e_i@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 11, build. 2.
ORCID: https://orcid.org/0000-0001-6605-4851

Ekaterina V. Rebrova — Cand. Sci. (Med.), Associate Professor of the Department of Clinical Pharmacology and Propaedeutics of Internal Diseases, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: rebrova_e_v@staff.sechenov.ru;
105043, Moscow, Izmaylovsky blvd, 8/31.
ORCID: https://orcid.org/0000-0002-4374-9754

Elizaveta N. Kytko — Student, F.F. Erisman Institute of Public Health, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: kytko_e_n@student.sechenov.ru
119435, Moscow, Bolshaya Pirogovskaya str., 2, build. 2.
ORCID: https://orcid.org/0009-0003-0670-5386

Sergey A. Tregubov — Student, N.F. Filatov Clinical Institute of Child Health, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: tregubovs01@yandex.ru
119435, Moscow, Bolshaya Pirogovskaya str., 19, build. 1.
ORCID: https://orcid.org/0000-0001-7315-8237

Artem D. Kashtanov — Clinical Resident of the Department of Anesthesiology and Resuscitation, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: kashtanov_a_d@staff.sechenov.ru;
119991, Moscow, Abrikosovsky lane, 2.
ORCID: https://orcid.org/0000-0002-9648-1720

Elena A. Son — Cand. Sci. (Med.), Associate Professor of the Department of Faculty Therapy No. 1, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: son_e_a@staff.sechenov.ru;
119435, Moscow, Bolshaya Pirogovskaya str., 6.
ORCID: https://orcid.org/0000-0002-5168-8752

Kirill A. Zhandarov — Cand. Sci. (Med.), Associate Professor of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: zhandarov_k_a@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0002-2908-6990

Natalia D. Ivanova — Teaching Assistant of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: ivanova_n_d@staff.sechenov.ru;

Контактная информация: voronova_e_i@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 11, стр. 2.
ORCID: https://orcid.org/0000-0001-6605-4851

Реброва Екатерина Владиславовна — кандидат медицинских наук, доцент кафедры клинической фармакологии и пропедевтики внутренних болезней Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: rebrova_e_v@staff.sechenov.ru;
105043, г. Москва, Измайловский б-р, 8/31.
ORCID: https://orcid.org/0000-0002-4374-9754

Кытько Елизавета Николаевна — студентка 1-го курса Института общественного здоровья им. Ф.Ф. Эрисмана, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: kytko_e_n@student.sechenov.ru
119435, г. Москва, ул. Большая Пироговская, 2, стр. 2.
ORCID: https://orcid.org/0009-0003-0670-5386

Трегубов Сергей Андреевич — студент 5-го курса Клинического института детского здоровья им. Н.Ф. Филатова, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: tregubovs01@yandex.ru
119435, г. Москва, ул. Большая Пироговская, 19, стр. 1.
ORCID: https://orcid.org/0000-0001-7315-8237

Каштанов Артем Денисович — клинический ординатор кафедры анестезиологии и реаниматологии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: kashtanov_a_d@staff.sechenov.ru;
117513, г. Москва, ул. Островитянова, 1.
ORCID: https://orcid.org/0000-0002-9648-1720

Сон Елена Алексеевна — кандидат медицинских наук, доцент кафедры факультетской терапии № 1 Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: son_e_a@staff.sechenov.ru;
119435, г. Москва, ул. Большая Пироговская, 6.
ORCID: https://orcid.org/0000-0002-5168-8752

Жандаров Кирилл Александрович — кандидат медицинских наук, доцент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: zhandarov_k_a@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0002-2908-6990

Иванова Наталия Дмитриевна — ассистент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: ivanova_n_d@staff.sechenov.ru;

119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0002-6047-4561

Dmitry S. Leonov — Teaching Assistant of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: leonov_d_s@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0009-0008-6855-2860

Hadi M.S. Darawsheh — Cand. Sci. (Med.), Teaching Assistant of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: daraushe_kh_m@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0002-1899-1282

Artem V. Mirontsev — Cand. Sci. (Med.), Teaching Assistant of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University).
Contact information: mirontsev_a_v@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0003-1783-694X

Sergey S. Dydykin — Dr. Sci. (Med.), Professor, Head of the Department of Operative Surgery and Topographic Anatomy, N.V. Sklifosovsky Institute of Clinical Medicine, I.M. Sechenov First Moscow State Medical University.
Contact information: dydykin_s_s@staff.sechenov.ru;
119992, Moscow, Rossolimo str., 15/13, build. 1.
ORCID: https://orcid.org/0000-0002-1273-0356

119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0002-6047-4561

Леонов Дмитрий Сергеевич — ассистент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: leonov_d_s@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0009-0008-6855-2860

Дарауше Хади Маджед Соуд — кандидат медицинских наук, ассистент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: daraushe_kh_m@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0002-1899-1282

Миронцев Артем Владимирович — кандидат медицинских наук, ассистент кафедры оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: mirontsev_a_v@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0003-1783-694X

Дыдыкин Сергей Сергеевич — доктор медицинских наук, профессор, заведующий кафедрой оперативной хирургии и топографической анатомии Института клинической медицины им. Н.В. Склифосовского, ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова» Министерства здравоохранения Российской Федерации (Сеченовский Университет).
Контактная информация: dydykin_s_s@staff.sechenov.ru;
119992, г. Москва, ул. Россолимо, 15/13, стр. 1.
ORCID: https://orcid.org/0000-0002-1273-0356

Authors' contributions

Concept and design of the study: Yuriy L. Vasil'ev, Tatyana M. Litvinova, Beatrice A. Volel, Marina A. Kinkulkina.
Collection and processing of the material: Artem D. Kashtanov, Natalia D. Ivanova, Kirill A. Zhandarov, Artem V. Mirontsev, Hadi M.S. Darawsheh, Dmitry S. Leonov, Elena A. Son, Sergey A. Tregubov, Olesya V. Kytko, Ekaterina V. Rebrova, Evgeniya I. Voronova, Elena O. Bakhrushina, Elizaveta N. Kytko.
Statistical processing: Yuriy L. Vasil'ev, Sergey S. Dydykin, Konstantin V. Ivashkin.
Writing of the text: Yuriy L. Vasil'ev, Konstantin V. Ivashkin.
Editing: Sergey S. Dydykin, Konstantin V. Ivashkin.

Вклад авторов

Концепция и дизайн исследования: Васильев Ю.Л., Литвинова Т.М., Волель Б.А., Кинкулькина М.А.
Сбор и обработка материалов: Каштанов А.Д., Иванова Н.Д., Жандаров К.А., Миронцев А.В., Дарауше Х.М.С., Леонов Д.С., Сон Е.А., Трегубов С.А., Кытько Е.Н., Реброва Е.В., Воронова Е.И., Бахрушина Е.О., Кытько О.В.
Статистическая обработка: Васильев Ю.Л., Дыдыкин С.С., Ивашкин К.В.
Написание текста: Васильев Ю.Л., Ивашкин К.В.
Редактирование: Дыдыкин С.С., Ивашкин К.В.

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