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Innovations in Medical Education in Gastrointestinal Surgery Using Interactive Anatomical Tables

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The introduction of digital technologies into the learning process for medical university students represents a new paradigm in medical education since high level of criteria for assessing the quality of learning of a medical student require the application of modern technologies in training fundamental disciplines and, in particular, anatomy. Thanks to virtual technologies, conditions are created for modeling and integrating the student into conditions close to real ones, which increases the interest and involvement of students in the educational process and, as a result, a subjective improvement in the process of assimilation of the material. Traditional education based on dissection materials cannot fully provide for the massive training of students, as biological materials cannot be restored or preserved and are quickly damaged. 3D models are devoid of these limitations.

Aim: to evaluate the effectiveness of digital dissection in the educational trajectory of clinical anatomy using interactive anatomical tables and the need of students for the active use of these aids.

Materials and methods. Four groups of students were formed: three groups were studying the material using various anatomical tables and one group used the traditional method. To control the effectiveness of the educational process, before the start of training, entrance testing was conducted in all groups. At the end of classes on individual topics, participants completed exit testing, as well as a questionnaire.

Results. The analysis of learning outcomes shows a significantly higher level of absorption of the material among students in groups where 3D anatomical models were used during classes. This indicates that students' subjective experience of the learning process has improved due to their increased involvement in the class and their interest in innovative teaching methods.

Conclusion. We plan to study learning outcomes in more detail to identify any differences in the formation of general and professional competencies among students. This information will help us make informed decisions about the widespread use of anatomical models in educational practice.

Keywords: medical education, bio digital, virtual anatomy, 3D virtual modeling, virtual dissection tables, biological dissection material, 3D modeling, knowledge control

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Инновации медицинского образования в хирургии желудочно-кишечного тракта с использованием интерактивных анатомических столов

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Внедрение цифровых технологий в процесс обучения студентов медицинских вузов является новой парадигмой медицинского образования, так как высокие критерии, предъявляемые к оценке качества подготовки врача, требуют использования современных технологий в преподавании фундаментальных дисциплин, и в частности анатомии. Благодаря симуляционным техникам создаются условия моделирования и интеграции обучающегося в условия, приближенные к реальным, что повышает интерес и вовлеченность студентов в образовательный процесс, и, как следствие, выявляется субъективное улучшение процесса усвоения материала. Классическое образование на анатомическом материале не может полностью обеспечить массовое обучение студентов, так как биологический материал не подлежит восстановлению и быстро повреждается — этих недостатков лишены цифровые трехмерные модели.

Цель исследования: оценить эффективность цифровой диссекции в образовательной траектории по клинической анатомии с использованием интерактивных анатомических столов и потребность обучающихся в активном применении указанных пособий.

Материалы и методы. Были сформированы 4 группы студентов: 3 группы изучали материал на различных анатомических столах, 1-я группа — по классической методике. Для контроля эффективности учебного процесса перед началом обучения во всех группах проведено входное тестирование. По окончании занятий по отдельным темам участники выполняли выходное тестирование, а также анкетирование.

Результаты. Анализ результатов обучения свидетельствует о значимо большем усвоении материала в группах, где во время занятий использовались трехмерные анатомические комплексы. Выявлено субъективное улучшение процесса усвоения знаний среди обучающихся за счет большей вовлеченности в образовательный процесс и повышения интереса к инновационным методикам проведения занятий.

Заключение. Результаты обучения будут изучаться в динамике, что позволит выявить различия в качестве формирования общепрофессиональных и профессиональных компетенций и послужит основой для принятия решения о повсеместном рутинном применении анатомических столов в образовательной практике.

Ключевые слова: медицинское обучение, цифровые технологии, трехмерная анатомия, трехмерное виртуальное моделирование, интерактивные анатомические столы, биологический материал, 3D-моделирование, контроль знаний

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Introduction

The widespread introduction of digital technologies into the process of teaching medical students in fundamental disciplines such as “Normal Human Anatomy” and “Topographic Anatomy and Operative Surgery” is one of the responses to the challenges of digital transformation, which has begun rapidly in the last five years. Among its goals, we can emphasize improving the quality of professional skills formation for future healthcare professionals and earlier immersion in a digital environment, where operations are already an integral part of the work of medical staff at various levels [1, 2]. The variety of interactive programs allows for their successful integration into the educational process. Methods of teaching anatomy using augmented reality and 3D virtual modeling technologies have become widespread in various areas of medicine, such as dentistry [3, 4], neurosurgery [5], general medicine, etc. The global trend in medical education technology is its maximum digitalization, particularly in the field of anatomy [6]. Classical education based on anatomical materials (both unfixed and fixed, including dissection materials) is not suitable for mass education, as biological materials cannot be restored or repaired and are quickly damaged.

Digital 3D models, on the other hand, do not have these limitations [7]. However, it is clear that the "gold standard" of clinical anatomy, dissection, cannot be replaced or supplemented by virtual and augmented reality. The tactile experience of dissection and the uniqueness of the human body provide the basis necessary for the development of clinical skills. According to S.K. Ghosh (2017), dissection alone cannot provide a uniform learning experience and must be supplemented by other innovative teaching methods in a future model of anatomy teaching [8]. The lessons we continue to learn from our experience of distance learning during the COVID-19 period show how learners are adapting to online learning. According to J. Khan et al. (2023), more than half of the study participants reported that they had adapted well to the online learning environment. However, the biggest challenge they faced was a sense of isolation due to the lack of practical training and hands-on experience [9–11].

Thus, we can assume that a modular approach to teaching clinical anatomy is effective, with dissection and work on anatomical materials as the final stage and interactive systems as an intermediate or calibration step. Given the apparent shortage of cadavers in some countries, the use of digital dissection could be a useful addition to the educational process, scientific planning, and clinical analysis. Modernization of medical education correlates with social development and the dissemination of gamification techniques in society [12–14]. An analysis of the literature has revealed that a new approach to the study of topographic anatomy, in the form of using interactive anatomical tables in the educational process, can help students to better understand the structure of the human body in three dimensions. This approach allows students to systematize and summarize information, as well as objectively evaluate their knowledge. This contributes to the development of students' competencies [15–17].

Today, it is clear that there is a significant shift in the approach to education in the medical field, at all levels, from nursing schools to higher education institutions [18, 19]. The conclusions drawn during the pandemic demonstrate the flexibility of interactive technologies, which, while not a replacement for the "gold standard" of dissection in anatomical education, do harmoniously complement it [15, 20]. In the context of the changing market and the emphasis on independent developments in digital technologies, Russian users now have access to domestic interactive anatomy tables, which are being actively introduced into the education system. Previously, we compared the technical and practical capabilities of devices like "Anatomage" and "Pirogov", providing valid data that allowed us to plan a comparative study of Russian interactive anatomy devices, considering the high standards for medical education quality [6].

The aim of this study: to assess the effectiveness of using digital dissection tools in the educational process of clinical anatomy, using interactive anatomical tables, and the need for students to actively engage with these resources.

To achieve this goal, we have set the following objectives:

1. To assess the initial level of knowledge among students before training in order to qualitatively select participants into groups.
2. To evaluate the efficacy of interactive anatomical tools in the learning process through comparative testing of student performance.
3. To obtain feedback from students regarding their impressions of using anatomical tables and the impact of their usage (Appendix).

Null Hypothesis

The effectiveness of the learning trajectory in clinical anatomy is higher for those students who use interactive anatomical tools as a supplement or reference material.

Materials and methods

For determining the sample size for a general population of 2,000 (total number of the second yest students of Medical Faculty at participating Universities (I.I. Mechnikov North-Western State Medical University; Russian University of Medicine; I.M. Sechenov First Moscow State Medical University (Sechenov University) and V.I. Razumovsky Saratov State Medical University). The sample size was determined using the following formula:

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

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

The study used domestic interactive anatomical tables, including "Pirogov" (LLC Razvitie), "Anatomograph" (LLC Bio veritas), and "PL-Anatomy TAB" (LLC Programmlab).

The distribution of participants across groups is shown in Table 1.

To monitor the effectiveness of the training program, an entrance test was administered to all participants before the start of the course. At the

Table 1. Distribution of study participants

Таблица 1. Распределение участников исследования

Comparison group ***Группа сравнения***	**Experimental groups** ***Экспериментальные группы***		**Control group*** ***Контрольная группа****	**Total number** ***Общее количество***
"Pirogov" *«Пирогов»*	"Anatomograph" *«Анатомограф»*	«PL-Anatomy TAB»	Traditional teaching methods *Традиционная методика обучения*	
90	45	30	165	330

Note: * — the control group was formed by uniform random sampling of students in each participating university.

Примечание: * — контрольная группа формировалась путем равномерной случайной выборки студентов в каждом вузе-участнике.

Figure. Practical classes with students at the following Universities: A — I.I. Mechnikov North-Western State Medical University; B — Russian University of Medicine; C — I.M. Sechenov First Moscow State Medical University; D — V.I. Razumovsky Saratov State Medical University

Рисунок. Практические занятия со студентами: A — ФГБОУ ВО «СЗГМУ им. И.И. Мечникова» Минздрава России; B — ФГБОУ ВО «Российский университет медицины» Минздрава России; C — ФГАОУ ВО «Первый МГМУ им. И.М. Сеченова» Минздрава России; D — ФГБОУ ВО «СГМУ им. В.И. Разумовского» Минздрава России

conclusion of each module, participants took an exit test and completed a questionnaire (Figure).

It is essential to consider the structural and technological features of the devices being used. The interactive anatomy "Pirogov" is a classic horizontal device with a low weight, as well as a mobile version that can be installed on any personal smartphone, creating a remote pairing in an educational setting. "Anatomograph" and "PL-Anatomy TAB" models, on the other hand, are represented by vertical interactive anatomical devices without a mobile version.

N.I. Pirogov (1810–1881), being the founder of clinical anatomy, is also known as an outstanding surgeon, whose skill and ability to foresee was ahead of time. After all, it is obvious that "Ice Anatomy" in many ways set a high level of diagnostic medicine, becoming the basis for radial methods of research [21].

By practicing cadaveric surgery techniques I.M. Pirogov managed not only to educate and train students in surgery with the absence of real patients, but also to support surgical skills of experienced surgeons in conditions of extremely rare operations. I.M. Pirogov believed that it was even easier to operate on patients than on cadavers [22].

Today, there is a shortage of anatomical material available for education in a number of countries. However, it is not a decrease in mortality but a lack of body donation programs that is responsible for this condition [23]. The lack of anatomical material not only creates problems of education and formation of doctors as specialists, but also negatively affects scientific activity. Attempts to replace cadavers are mainly aimed either to use material of animal origin, or synthetic material at all. A relative compromise was 3D anatomy, which can supplement the scarce range of educational anatomical fixed material, as well as be a calibration tool during young doctors' education. For instance, interactive anatomy table "Pirogov", which combines both a 3D human model and the famous "Ice Anatomy".

It is important to note that the "PL-Anatomy TAB" and "Anatomograph" models can change the angle of inclination from vertical to horizontal, potentially increasing student compliance due to greater user orientation compared to the "Pirogov" table. Additionally, the larger size of the "Pirogov" table (730 × 2250 with a resolution of 3840 × 1080 pixels) compared to the "PL-Anatomy TAB" (1180 650 with a resolution of 3840 2160 pixels) may also appeal to users. A general comparison of the anatomical tables is provided in Table 2.

The study was conducted in accordance with the rules and principles of the Helsinki Declaration of the World Medical Association. The study was supported by the Ethics Committee of Sechenov University (Protocol No. 16-23 dated September 14, 2023).

The results of the questionnaire and input and output tests were analyzed using IBM SPSS Statistics 26 and Microsoft Excel 2016.

Results

The assessment of the studied qualitative characteristics in all the surveyed groups, including gender, age, and degree of satisfaction with learning, revealed that the null hypothesis of normality of distribution was not supported. Therefore, additional methods of non-parametric statistical analysis were employed to analyze the data.

The analysis of the experience with interactive educational methods and the time spent using a computer for extra-curricular activities is presented in Table 3, along with the results of this analysis.

The null hypothesis of normality of distribution was not supported, and therefore, nonparametric methods of statistical analysis were employed to analyze the data. The results of the analysis of the average values of respondents' overall satisfaction according to various criteria of the educational process are presented in Table 4. The results of the analysis of the data of the entrance testing in the study groups are presented in Table 5.

When analyzing the data from the input testing, we found differences in trends (Mann — Whitney U-test, $p = 0.021$), indicating an increase in the number of points scored in the output testing for both the control and experimental groups. The increase in test scores for the output testing was higher in the experimental group compared to the comparison group. This can be explained by the improved consolidation of knowledge gained through the use of an interactive 3D complex during training. The results of the average values for the input and output tests are presented in Table 6.

The analysis of the effectiveness of training in the comparison and experimental groups, based on the results of the input and output tests, showed statistically significant differences. The Mann — Whitney U-test showed a p-value of less than 0.001, indicating a strong level of significance.

Discussion

During the analysis of the results, the null hypothesis of the study was confirmed. The findings suggest that teaching students with the anatomical table and mobile version of "Pirogov" is more effective than using "Anatomograph". However,

Table 2. General characteristics of the educational aids used

Таблица 2. Общая характеристика используемых образовательных пособий

Characteristics ***Характеристика***	**Table used** **Используемый стол**		
	"Pirogov" ***«Пирогов»***	**"Anatomograph"** ***«Анатомограф»***	**«PL-Anatomy TAB»**
Dimensions, mm *Размер, мм*	900 × 760 × 1490	1137 × 667 × 955	900 × 820 × 1500
Screen diagonal, inches *Диагональ экрана, дюймы*	50	49	50
Ability to change the angle of inclination to the surface *Возможность менять угол наклона к поверхности*	No *Нет*	Yes *Да*	No *Нет*
Number of simultaneous touches *Количество одновременных касаний*	2	20	10
Knowledge control *Контроль знаний*	No *Нет*	Yes *Да*	No *Нет*
Ability to modulate pathologies *Возможность модуляции патологий*	Limited *Ограничено*	Yes *Да*	No *Нет*
Availability of a mobile application *Наличие мобильного приложения*	Yes *Да*	No *Нет*	No *Нет*
Connection of VR technology *Подключение VR технологии*	No *Нет*	No *Нет*	Yes *Да*

Table 3. Results of the analysis of the experience in using interactive educational methods and the duration of computer use for extracurricular purposes

Таблица 3. Результаты анализа опыта использования интерактивных образовательных методик и длительности использования компьютера во внеучебных целях

Group ***Группа***	**Had there been any experience of using anatomical programs?*** ***Был ли опыт использования анатомических программ?*** ***n* (%)**		**Computer use outside of academic purposes, hours per week**** ***Использование компьютера вне учебных целей, кол-во часов в неделю**** ***n* (%)**
Control *Контрольная*	yes / *да*	36 (13.3 %)	7.96
	no / *нет*	99 (36.7 %)	9.83
Comparison *Сравнения*	yes / *да*	51 (18.9 %)	4.78
	no / *нет*	39 (14.4 %)	6.13
Experimental *Экспериментальная*			
"Anatomograph" *«Анатомограф»*	yes / *да*	18 (6.7)	3.12
	no / *нет*	27 (10 %)	2.89
«PL-Anatomy TAB»	yes / *да*	19 (63.3 %)	3.31
	no / *нет*	11 (36.7 %)	3.45

Note: Fisher's exact test (φ) was used in the analysis; * — the obtained empirical value of φ (3.11) is in the significance zone, H0 is rejected; ** — the obtained empirical value of φ (2.08) is in the significance zone, H0 is rejected.

Примечание: при анализе использовался точный тест Фишера (φ-критерий); * — полученное эмпирическое значение φ-критерия (3,11) находится в зоне значимости, H0 отвергается; ** — полученное эмпирическое значение φ-критерия (2,08) находится в зоне значимости, H0 отвергается.

Table 4. Assessment of satisfaction with training among respondents
Таблица 4. Оценка удовлетворенности обучением у респондентов

	Group / *Группа*				*p**
	Control *Контрольная*	Comparison *Сравнения*	Experimental *Экспериментальная*		
			"Anatomograph" *«Анатомограф»*	«PL-Anatomy TAB»	
Degree of participation in this method of presenting the material *Степень участия в данном способе подачи материала*	3.1	3.6	3.8	4.3	
Meeting expectations from the program *Оправдание ожиданий от программы*	2.6	4.0	4.1	4.0	
Visual usefulness of the lesson *Визуальная полноценность занятия*	2.3	4.4	4.1	4.6	
Method of presenting the material *Способ подачи материала*	2.3	4.7	4.5	4.7	
Educational value of the teaching method *Образовательная ценность методики преподавания*	3.1	4.5	4.4	4.7	
Usefulness of the teaching method in terms of mastering knowledge in the future *Полезность методики преподавания с точки зрения овладения знаниями в будущем*	3.5	4.3	4.3	4.6	
Stress/discomfort during entrance testing *Стресс/дискомфорт на входном тестировании*	3.0	2.8	2.6	2.5	
Stress/discomfort during exit testing *Стресс/дискомфорт на выходном тестировании*	3.2	3.2	2.9	2.4	
Overall satisfaction (*Me*) *Общая удовлетворенность (Me)*	3.1	4.2	4.1	4.6	0.013

Note: *p* — the significance level determined using the Mann — Whitney test; * — differences are statistically significant at $p < 0.05$.

Примечание: *p* — уровень значимости, определенный с применением критерия Манна — Уитни; * — различия статистически значимы при $p < 0,05$.

it should be noted that there was a significant increase in correct responses in the "Anatomograph" group, despite the low initial scores on the entrance test. The use of the "Anatomograph" was also associated with a reduced psychological stress level among students, as evidenced by lower stress levels on the entrance and exit tests and a greater level of participation in presentations. The greatest satisfaction and lowest stress were reported in the "PL-Anatomy TAB" group, which is likely due to the improved ergonomics of the manual. For further research, it would be interesting to consider a combination of these devices in order to improve both the overall effectiveness of the teaching methodology and the student's learning compliance. The introduction of the "PL-Anatomy TAB" table into the teaching practice has significantly improved the quality of education and the students' assimilation of the material. In the study on the effectiveness of training with the "PL-Anatomy TAB" table, we found that the positive impact of training does not depend on the previous experience with similar programs or 3D anatomical models. This means that it is possible

Table 5. Learning efficiency in points (*Me*)

Таблица 5. Эффективность обучения в баллах (*Me*)

Testing *Тестирование*	Group / *Группа*				*p**
	Control *Контрольная*	Comparison ("Pirogov") *Сравнения («Пирогов»)*	Experimental / *Экспериментальная*		
			"Anatomograph" *«Анатомограф»*	«PL-Anatomy TAB»	
Entrance *Входное*	4.2	2.43	3.3	3.33	0.013
Exit *Выходное*	4.77	4.53	4.8	4.47	0.017

Note: *p* — the significance level determined using the Mann — Whitney test; * — differences are statistically significant at $p < 0.05$.

Примечание: *p* — уровень значимости, определенный с применением критерия Манна — Уитни; * — различия статистически значимы при $p < 0,05$.

Table 6. Estimation of the average values of the percentage of correct completion of the entrance and exit testing in the experimental group and the group of comparison (*Me, %*)

Таблица 6. Оценка средних значений процента правильного выполнения входного и выходного тестирования у экспериментальной группы и группы сравнения (*Me, %*)

Testing *Тестирование*	Group / *Группа*			*p**
	Experimental *Экспериментальная*		Comparison ("Pirogov") *Сравнения («Пирогов»)*	
	"Anatomograph" *«Анатомограф»*	«PL-Anatomy TAB»		
Entrance / *Входное*	24.33	33.34	41.67	0.001
Exit / *Выходное*	45.33	42.34	59.5	0.004
Increase in percentage of correct answers to the initial level *Прирост процента правильного выполнения к исходному уровню*	21.0	9	17.83	0.037

Note: *p* — the significance level determined using the Mann — Whitney test; * — differences are statistically significant at $p < 0.05$.

Примечание: *p* — уровень значимости. определенный с применением критерия Манна — Уитни; * — различия статистически значимы при $p < 0,05$.

to use the anatomical table effectively even without prior training, making it a valuable tool for teaching anatomy.

The data obtained in this study are consistent with previous studies, including those conducted by foreign researchers [9, 15, 24], as well as those conducted in our own country [3, 4, 6]. 3D virtual modeling is widely used in anatomy and surgery today [25, 26], and the data from a systematic review conducted by N. Jayakumar et al. (2015) indicate the need for introducing virtual and augmented reality into training at both pre- and post-graduate levels [27]. However, there are some limitations to this approach, such as the commercialization of anatomical atlases and the absence of a standardized model [28–30], which have been addressed in this study.

Therefore, we propose the following **teaching methodology for using an anatomical model**:

1. *Study the topic using lecture materials in an online format.* According to a study conducted by L. Lochner et al. in 2016, the inclusion of lecture materials increases the "life span" of knowledge in memory [9]. The experience during the COVID-19 pandemic has demonstrated that the assimilation of knowledge from online lectures is comparable to that from face-to-face lectures. However, students prefer online lectures as they provide the opportunity to acquire knowledge "anywhere", despite the absence of direct contact with the group [11, 31].

2. *Study the material using a table during two academic classes.* This stage requires more time than a regular practical lesson, as each student needs to work with the anatomical model individually. It is important that each model is correctly labeled from an anatomical perspective — in accordance with the latest anatomical terminology

TA2 [32]. Virtual reality anatomy training and gamification are discussed separately in this section, but today there is no opportunity for mass, one-time training in a "virtual classroom" format [26, 30, 33].

3. *Interim assessment of the material covered.* The proposed training method allows for both fewer hours of teaching and increased student flexibility, which enhances learning compliance. So today, more than 700 students from the I.I. Mechnikov North-Western State Medical University and 600 students from the I.M. Sechenov First Moscow State Medical University have already had access to the online atlas and are using it to prepare for practical classes and current and intermediate certifications. Interactive anatomical tables are regularly used in the Department of Topographic Anatomy and Operative Surgery at the I.M. Sechenov First Moscow State Medical University, and their mobile versions are distributed to students as part of practical classes and interim exams. In the future, learning outcomes will be monitored in real-time, which will help identify differences in the quality of formation of general and professional skills and will serve as a basis for deciding on the widespread use of anatomical models in educational practice.

Conclusion

1. During the study, the null hypothesis was confirmed — the use of interactive anatomical tables significantly improved the quality of educational methods. This is reflected in the positive trend in the results of group testing.

2. The high educational value and effectiveness of technology with a mobile version have been revealed when compared to other models. The combination of a stationary device and a "pocket" version ensures access to knowledge regardless of the student's location.

3. The use of vertical interactive anatomical tables has shown high satisfaction with the teaching methodology and low levels of situational stress among students. This, apparently, is due to the ergonomic design of the devices.

4. An assessment of the effectiveness of using interactive anatomical programs in the educational process has been conducted. The analysis of learning outcomes shows a significantly better assimilation of material in groups that used 3D anatomical models during classes. This was due to the subjective improvement of the learning experience for students, as they were more engaged in the educational process and showed increased interest in the innovative teaching method.

Appendix
A typical questionnaire for respondents

1. Gender
2. Age
3. City
4. How much time per week do you spend on non-academic computer-related activities?
5. Have you previously used an interactive anatomy program or table? If so, please specify which one.

Please describe your thoughts on the educational approach, in accordance with the following table:

No.	Question	Very bad	Bad	Satisfied	Good	Very good
1	Evaluate your participation in this presentation method of the material.					
2	Evaluate how well your expectations were met regarding submitting and mastering the lesson material based on the results.					
3	Assess the visual organization of the lesson.					
4	How satisfied are you with the teacher's presentation of the material (lesson topic)?					
5	In your opinion, how valuable is the way the educational material is presented in the classroom?					
6	Evaluate the usefulness of this method of presenting material for mastering knowledge in the future.					
7	What is your opinion about the teacher?					
8	Evaluate your stress/discomfort during the entrance test.					
9	Evaluate your stress/anxiety on exit test.					
10	Evaluate ergonomic comfort of the device.					
11	Evaluate navigation in the program.					

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