

DOI 10.22363/2313-0245-2025-30-1-55-65  
EDN CYQPQBORIGINAL RESEARCH  
ОРИГИНАЛЬНОЕ ИССЛЕДОВАНИЕ

## Employing seamless mesh implants during Lichtenstein hernia repair with the use of insights enabled by artificial intelligence

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**Abstract. Relevance.** Globally, there are now 32.53 million hernia cases, up from about 23.92 million during the previous 3 decades. Many authors lack statistical knowledge, which could jeopardize healthcare. *The aim* was to use artificial intelligence as a statistical technique to assess the potential effects of Adhesix™ self-gripping mesh implants, Hertra™ mesh implants, and Lintex™ glue-fixed mesh implants on the outcomes of inguinal hernia patients who underwent open inguinal hernia repair in Lichtenstein. *Materials and Methods.* We performed 120 Lichtenstein-compliant inguinal hernia repair procedures on three evenly split patient groups (n = 40) using Adhesix™, Hertra™, and Lintex™ mesh implants. The parameters for comparison were the time-frame of the procedure, hospital-stays, challenges afterwards surgery, and issues that arose during the brief follow-up. *Results and Discussion.* Patients of the first group were hospitalized for shorter periods of time than those in the second and third groups (group A-4.9 bed /day, group B-4.9.5 bed /day, and group C-4.95 bed /day), with no statistically significant differences. Patients in the first group experience a significantly shorter procedure time, followed by those in the second and third groups (27.8 min, 31.4 min, and 38.9 min respectively). Unlike the third group, which included 3 patients with postoperative discomfort and 1 with postoperative seroma formation, the first and second groups' postoperative hospitalization stays were free of complications. In contrast to the third group's 2 patients who experienced mesh migration and hernia recurrence, the first and second groups' patients experienced no complications during the short-term follow-up. *Conclusion.* Compared to Lintex™ mesh implants, the operative times using Adhesix™ and Hertra™ are significantly shorter with no post-operative complications or hernia recurrence.

**Keywords:** hernia, mesh implants, polypropylene, glue, artificial intelligence

**Funding.** The authors received no financial support for the research, and publication of this article.

**Author contributions.** M.Sh.F. Mekhaeel, S.M.A. Salem — concept and design of the study; Protasov A.V. — editing the manuscript. All authors made significant contributions to the conception, conduct of the study and preparation of the article, read and approved the final version before publication.

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**Conflicts of interest statement.** Authors declare no conflict of interest.

**Ethics approval.** The study was approved by the bioethics commission of the Federal State Budgetary Institution Research Institute of Human Morphology (Protocol № . 3, 01.02.2019).

**Acknowledgements.** Authors express profound gratitude to the medical team at clinical hospital No. 85 Federal Medico Biological Agency (FMBA), Moscow, Russian Federation, particularly the nurses and residents in the clinical anatomy and operative surgery department, who assisted us in finishing this study work. Our gratitude also goes go to the patient who agreed to have his case taken and published.

**Consent for publication.** All patients provided informed voluntary consent to participate in the study according to the Helsinki Declaration of the World Medical Association (WMA Declaration of Helsinki — Ethical Principles for Medical Research Involving Human Subjects, 2013) and personal data processing.

Received 04.06.2025 Accepted 01.07.2025.

**For citation:** Protasov AV, Mekhaeel MShF, Salem SMA. Employing seamless mesh implants during Lichtenstein hernia repair with the use of insights enabled by artificial intelligence. *RUDN Journal of Medicine*. 2026; 30(1):55–65. doi: 10.22363/2313-0245-2026-30-1-55-65. EDN: CYQPQB

## Introduction

When it comes to surgical mesh fabrication, polypropylene (PP) is the most widely used material worldwide [1]. It is nonabsorbable, electrostatically neutral, extremely hydrophobic, nonpolar, and has a high tensile strength. It can be found in mono or multifilaments, coated or uncoated, heavy or lightweight forms [2]. Fuse Deposition Modelling (FDM) in 3D printing surgical meshes [3] reduces the tensile strength of the mesh and creates multiple contact points between the mesh and surrounding tissues, as opposed to the mobile joint points that are achieved through knitting in non-pre-shaped meshes. This results in a significant reduction in both operative time and postoperative pain [4].

In terms of surgical time, postoperative seroma/hematoma production, urinary retention, and even more, recurrence rates, the use of pre-shaped surgical meshes is better to that of non-pre-shaped suture-fixed ones [5, 6]. Many theories explain why the application of self-adhering pre-shaped meshes causes less postoperative pain than sutured ones by linking the pathophysiology of early postoperative

inguinal pain to not only surgery-related causes but also tissue trauma from surgical field preparation, mesh inflammatory reaction, and mesh fixation. Furthermore, cost-effective research demonstrated that self-adhering pre-shaped meshes were more cost-effective to use than ordinary sutured meshes, despite their higher price [7, 8].

Tissue adhesives have been proposed as an alternative to permanent fixation devices in hernia repair with the aim of reducing perforation-associated complications and chronic pain. The adhesives can be divided into three main categories: biologic products (e.g., fibrin), synthetic glues (e.g., cyanoacrylate based), and genetically engineered polymer protein glues. Fibrin sealant has been used extensively in all surgical disciplines for tissue adhesion, suture support, hemostasis, wound care, and endoscopic treatment of bleeding. Cyanoacrylate based glues have been investigated in numerous scientific studies as hemostatic agents, topical dressing, and adhesives in soft tissues, in ophthalmology, odontostomatology, osteosynthesis of bone fracture and, recently, as drug carriers. They were also used in gastroenterology for

esophagus varix treatment, in maxillo-facial surgery, and in vascular surgery for arterious anastomoses [9].

The accuracy of diagnoses, clinical judgment, and patient outcomes have all been transformed by the application of artificial intelligence and statistical science in medicine, especially surgery. The crucial significance statistical frameworks play in organizing and approving medical research is shown by current research. When assessing clinical outcomes, especially in surgical operations, fundamental statistical parameters like sensitivity, specificity, and predictive values are still crucial. Likewise, statistically verified artificial intelligence (AI) models improve surgical accuracy and outcome prediction [10,11].

Another popular statistical technique is regression analysis, for which Lee suggests standardized uses for continuous variables in clinical research [12]. Machine learning algorithms are becoming more widely used in a variety of fields, including radiology and surgical risk assessment. These algorithms provide doctors with dynamic models that get better with time and additional data [13]. The strength of statistical science in controlling chronic illnesses is further demonstrated by the use of machine learning in complicated areas, such as blood glucose prediction in Type 1 diabetes. In this situation, the precision, scalability, and reproducibility of research are greatly impacted by the data analysis methods selected. Although many people use Microsoft Excel for simple data management and visualization, Python offers more flexibility and computational resilience. With the help of libraries like Pandas, NumPy, SciPy, and scikit-learn, Python allows for sophisticated statistical modeling, real-time data analysis, and automation on a scale that Excel is unable to rival [14, 15].

The growing relevance of machine learning in medical research was reviewed by Garg and Mago [16], who emphasized how Python makes it easier to construct algorithms for diagnostic and therapy planning. Additionally, Fang explains how statistical techniques guarantee increased reproducibility and transparency in biological research when applied using programming environments such as Python. Additionally, Python is a better option for medical

researchers working with high-dimensional clinical datasets due to its connection with hospital information systems and compatibility with big data platforms. With these developments, Python is now more suited to construct intelligent healthcare systems and serves as a supplement to statistical science [17].

The aim of this work is to enhance the results of Lichtenstein, the gold standard technique for anterior hernia repair [18], given that the global market for hernia repair is expected to reach \$6.3 billion in the next few years [19].

## Materials and methods

### Patients

Between January 2022 and March 2025, our team conducted 120 patients with inguinal hernias who underwent anterior inguinal hernioplasty with seamless implants during Liechtenstein. The study took place at RUDN University's Department of Operative Surgery and Clinical Anatomy, located at the Clinical Federal Hospital № 85 in Moscow, Russia. We used patient card control, which allowed us to select all of the relevant help criteria. As summarized in Table 1.

### Inclusion criteria

1. Patients with a unilateral, main inguinal hernia and no additional hernias.
2. Patients in the age range of 21 to 71.
3. Both men and non-pregnant women.
4. Patients were treated using the Lichtenstein method.
5. Patients beforehand.

### Disqualification standards

1. People who have bilateral, recurrent inguinal hernias or other hernias that occur concurrently are excluded.
2. Individuals who are over 71 or under 21.
3. Expectant mothers.
4. Patients who expressed their desire for laparoscopic surgery.
5. Individuals in need of urgent care.

Table 1

Control card for the patients

<ol style="list-style-type: none"> <li>1) Admission timing and date.</li> <li>2) The release date and time.</li> <li>3) Total hospital stay (beds per day).</li> <li>4) <u>Preoperative information on the patient:</u> <ol style="list-style-type: none"> <li>a. Name, surname, and middle name.</li> <li>b. The card's number.</li> <li>c. Gender.</li> <li>d. Age.</li> <li>e. Profession.</li> <li>f. Address.</li> <li>g. Telephone number.</li> <li>h. Patient grievance.</li> <li>i. The length of the hernia.</li> <li>j. Hernia size.</li> <li>k. Hernia site (left or right).</li> <li>l. Type of hernia: direct or oblique.</li> <li>m. The external inguinal ring's dimensions.</li> <li>n. Related comorbidities: assessing the influence of connective tissue diseases and figuring out the risk factors affecting the patient's quality of life.</li> </ol> </li> <li>5) <u>Information obtained during surgery:</u> <ol style="list-style-type: none"> <li>a. Anesthesia kind.</li> <li>b. The mesh implant that was used (kind, size, and technique of anchoring the mesh).</li> <li>c. Size of the hernial sac.</li> <li>d. Surgery-related issues.</li> <li>e. Time of operation.</li> </ol> </li> <li>6) <u>Post-operative care:</u> <ol style="list-style-type: none"> <li>a. Complications during hospitalization.</li> <li>b. Concerns arose during the six-month postoperative short-term follow-up.</li> </ol> </li> </ol>
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**Research methodology**

A combination of a prospective and retrospective analysis.

For the purposes of our investigation, we divided the 120 participants in our clinical trial into three equal groups (n = 40).

Adhesix™ self-gripping mesh implants (Figure 1) were used in Group A; 40 male patients make up this

group. The average age was 51.45. Thirty-two patients had a right inguinal hernia, while eight patients had a left. There is a 24:16 ratio of oblique to straight inguinal hernias. The averages of age, duration of herniation, hernial and external hernial ring, are summarized in Table 2.

Table 2

Averages of age, duration of herniation, dimensions of hernia and external hernial ring for group A

Metric	Mean	Standard Error	Median	Mode	Standard deviation	Range	Min	Max
Age (years)	51.45	3.03	53	70	13.56	43	27	70
Duration of Herniation (months)	24.75	8.58	7.5	6	38.39	117	3	120
Hernia Length (cm)	6.9	0.61	6	6	2.71	9	3	12
Hernia Width (cm)	4.68	0.28	4.5	4	1.26	4.5	2.5	7
Hernia Height (cm)	3.75	0.45	3.5	3	1.28	4	2	6
Hernia Volume (cm³)	85.35	21.11	39	12	94.41	276	12	288
External Inguinal Ring Size (cm)	2.5	0.11	2.5	2.5	0.51	2	1.5	3.5

Hertra™ pre-fitted mesh implants (Figure 2) were used in Group B; 36 men and 4 women. 55.95 years old was the average. This group consists of twenty patients with right inguinal hernias and twenty patients with left inguinal hernias. Oblique to direct inguinal hernias is 20:20 in ratio. The averages of age, duration of herniation, hernial and external hernial ring, are summarized in table 3.

Glue-repaired Lintex™ mesh implants (Figure 3) were used in Group C; there were also 14 female patients and 26 male patients. The average age was 58.89 years. Of the patients, 26 had a right inguinal hernia and 14 had a left. 21:19 is the oblique to direct inguinal hernia ratio. The averages of age, duration of herniation, hernial and external hernial ring, are summarized in Table 4.

**Table 3****Averages of age, duration of herniation, dimensions of hernia and external hernial ring for group B**

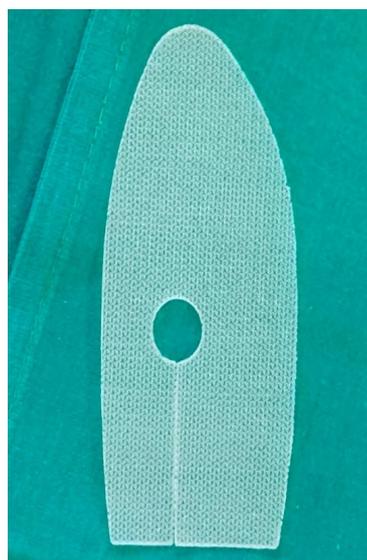
Metric	Mean	Standard Error	Median	Mode	Standard deviation	Range	Min	Max
Age (years)	55.95	2.96	63	64	13.26	41	27	68
Duration of Herniation (months)	22.7	4.41	18	24	19.70	58	2	60
Hernia Length (cm)	7.35	0.88	6	5	3.95	13	2	15
Hernia Width (cm)	4.7	0.33	4.5	4	1.49	5	2	7
Hernia Height (cm)	3.29	0.61	3	2	1.60	4	2	6
Hernia Volume (cm <sup>3</sup> )	86.3	28.05	31	25	125.46	498	6	504
External Inguinal Ring Size (cm)	2.35	0.19	2.5	1.5	0.83	2.5	1.5	4

**Table 4****Averages of age, duration of herniation, dimensions of hernia and external hernial ring for group C**

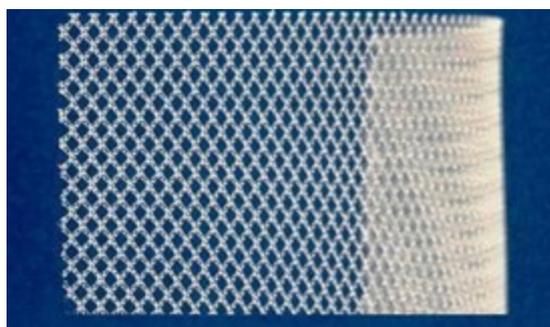
Metric	Mean	Standard Error	Median	Mode	Standard deviation	Range	Min	Max
Age (years)	58.89	1.66	62	62	10.07	40	30	70
Duration of Herniation (months)	58.89	1.66	24	24	39.13	178	2	180
Hernia Length (cm)	58.89	1.66	7	6	3.71	15	2	17
Hernia Width (cm)	58.89	1.66	4	4	1.83	8	2	10
Hernia Height (cm)	58.89	1.66	3	3	1.79	7	2	9
Hernia Volume (cm <sup>3</sup> )	58.89	1.66	48	48	259.29	1524	6	1530
External Inguinal Ring Size (cm)	58.89	1.66	25	25	0.76	2.5	1.5	4



**Fig. 1.** Adhesix™ self-gripping mesh implant



**Fig. 2.** Hertra™ pre-fitted mesh implant



**Fig. 3.** Glue-repaired Lintex™ mesh implant

The main complaints of the patients are summarized in Table 5.

After collecting the medical histories of the patients in the three groups, we discovered the following comorbidities as summarized in Table 6.

**Table 5**

**Main complaints of the patients**

	Group A	Group B	Group C	Grand total
Painless Slowly growing inguinal mass	30/40 (75%)	18/40 (45%)	17/40 (42.5%)	65/120 (54.167%)
Constant inguinal pain during rest	3/40(7.5%)	7/40 (17.5%)	10/40(25%)	20/120 (16.67%)
Groin pain during standing	4/40(10%)	7/40 (17.5%)	6/40(15%)	17/120(14.167%)
Groin pain upon lifting heavy objects	2/40(5%)	6/40(15%)	7/40(17.5%)	15/120(12.5%)
Pulling pain in the groin	1/40(2.5%)	2/40(5%)	0/40(0%)	3/120(2.5%)
Grand total	40/40 (100%)	40/40 (100%)	40/40(100%)	120/120(100%)

Table 6

Patients' associated comorbidities				
	Group A	Group B	Group C	Grand total
HTN	-	-	2/40 (5%)	2/120 (1.67%)
HTN+CHF	-	10/40 (25%)	4/40 (10%)	14/120 (11.67%)
HTN+CHD	-	4/40 (10%)	2/40 (5%)	6/120 (5%)
HTN+ Ch. Gastritis	-	4/40 (10%)	2/40 (5%)	6/120 (5%)
HTN+ Ch. Cal. Cholecystitis	-	2/40 (5%)	1/40 (2.5%)	3/120 (2.5%)
HTN+ Varicose veins	-	2/40 (5%)	1/40 (2.5%)	3/120 (2.5%)
HTN+ Type II D.M.	-	2/40 (5%)	1/40 (2.5%)	3/120 (2.5%)
HTN+ Dyslipidemia	-	2/40 (5%)	-	2/120 (1.67%)
HTN+AF	-	-	1/40 (2.5%)	1/120 (0.83%)
Sinus Bradycardia	-	-	1/40 (2.5%)	1/120 (0.83%)
COPD	2/40 (5%)	-	1/40 (2.5%)	3/120 (2.5%)
Varicose veins	4/40 (10%)	-	1/40 (2.5%)	5/120 (4.17%)
Urolithiasis	-	-	1/40 (2.5%)	1/120 (0.83%)
Type II D.M.	2/40 (5%)	-	-	2/120 (1.67%)
Grand total	8/40 (20%)	26/40 (65%)	18/40 (45%)	52/120 (43.3%)

### Statistical analysis

The statistics module of the Python programming language, which is machine learning-based statistical software with artificial intelligence support, was used to perform the calculations. Descriptive statistics, such as arithmetic mean (M), standard error, median, mode, standard deviation (s), range, minimum (Min), and maximum (Max), were used to statistically examine the collected data. Windows 11 was the operating system. 8 GB of RAM is needed for the system.

## Results and discussion

### The comparison-based criteria

#### I. The time for operation.

The average operating time for patients in group (A) who had surgery with Adhesix™ self-gripping mesh implants was 27.8 minutes; for patients in group (B)

who had surgery with Hertra™ mesh implants fixed by a single polypropylene suture to the pubic bone, it was 31.4 minutes; and for patients in group (C) with Lintex™ glue-fixed mesh implant was 38.9 minutes as summarized in Table 7.

The average operating duration of 3.6 minutes does not appear to differ statistically significantly between groups A and B, according to the p-value of 0.90.

The p-value (< 0.0001) shows a statistically significant difference in operative time between groups A and C, with an average of roughly 11.1 minutes.

The p-value (< 0.0001) shows a statistically significant difference in the average operating duration (~7.5 minutes) between groups (B) and (C).

In terms of operating time, these figures show a statistically significant difference between the use of Adhesix™ self-gripping mesh, Hertra™ mesh fastened by single stitch, and Lintex™ mesh fixed by glue.

Table 7

The average operative-time for the 3 group

Metric	Group A(Adhesix™)	Group B(Hertra™)	Group C (Lintex™)
Mean	27.8	31.4	38.9
Standard Error	1.5	1.76	2.17
Median	26.5	28.1	33.75
Mode	25	28.1	30
Std Dev	6.7	7.88	13.24
Range	21.8	30.6	63.75
Min	21	26.25	18.75
Max	38	35	82.5

### II. Hospitalization (day/bed)

Hospital stays for group (A) patients who had surgery with Adhesix™ self-gripping mesh implants lasted an average of 4.9 days; group (B) patients who had surgery with Hertra™ mesh implants that were secured to the pubic bone with a single polypropylene suture lasted 4.95 days; and group (C) patients who had surgery with Lintex™ implants that were secured with glue lasted 4.95 days, as summarized in Table 8.

The average length of stay in the hospital was about five days, similar for all groups.

The p-value of 0.90 indicates that there is no statistically significant difference in the length of hospitalization for either group.

These numbers showed that the three study groups' hospital stays did not differ statistically significantly.

### III. Recovery issues after surgery

During their hospital stay following surgery, we found that everyone in group (A) was trouble-free.

No problems exist between any of the group members for the patients in group (B).

Conversely, we found that three patients in group (C) had postoperative pain that was reduced following NSAID use. One patient had seroma. The other group members did not experience any pain. During the hospital stay following surgery, none of the patients in group (C) experienced any further issues.

Table 8

Hospitalization (day/bed)

Metric	Group A(Adhesix™)	Group B(Hertra™)	Group C (Lintex™)
Mean	4.9	4.95	4.95
Standard Error	0.34	0.23	0.19
Median	4.5	5	5
Mode	4	5	5
Std Dev	1.52	1.05	1.15
Range	5	4	5
Min	3	3	3
Max	8	7	8

#### IV. Issues with the short-term follow up.

During the six-month short-term follow-up, we noticed that all of the patients in group (A) had no issues. There were no repetitions. There are no problems among the patients in Group (B). There were no repetitions. Among the patients in group (C), we found two who had mesh migration and recurrence.

So, the three types of seamless implants that Lichtenstein uses for open inguinal hernioplasty are self-gripping mesh (Adhesix), mesh implants (Hertra) that are fastened to the pubic bone with a single wire, and mesh implants (Lintex) that are fixed with glue.

Discussion 1. Patients who had surgery in the first group were hospitalized for shorter periods of time than those in the second and third groups (group A-4.9 b/d, group B-4.9.5 b/d, and group C-4.95 b/d), but there were no statistically significant differences.

Discussion 2. Patients in the first group take a lot less time to complete the process than patients in the second and third groups (groups A, B, and C, respectively; 27.8 minutes, 31.4 minutes, and 38.9 minutes).

Discussion 3. Unlike the third group, which included three patients with postoperative discomfort and one with postoperative seroma formation, the first and second groups' postoperative hospitalization stays were free of complications.

Discussion 4. Unlike the third group, which included two patients with mesh migration and hernia recurrence, the first and second group patients experienced no complications during the short-term follow-up.

### Conclusion

Compared to Lintex mesh implants, the operative times for inguinal hernioplasty with an anterior approach using self-gripping mesh (Adhesix), mesh implants (Hertra) fixed by a single polypropylene to the pubic bone, and mesh implants (Lintex) fixed by glue are significantly shorter (11. minutes and 7.5 minutes, respectively). In contrast to Lintex™, which experienced three post-operative pain cases and one seroma case, Adhesix™ and Hertra™ experienced no issues during

the post-operative hospital stay. In the short-term follow-up, the first group experienced no issues, the second group experienced none, and the third group experienced two mesh migrations and a hernia recurrence.

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## Использование бесшовных сетчатых имплантатов при герниопластике по методу Лихтенштейна с использованием технологий искусственного интеллекта

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**Аннотация.** *Актуальность.* В настоящее время во всем мире зарегистрировано 32,53 миллиона случаев грыжи, по сравнению с примерно 23,92 миллионами за предыдущие 3 десятилетия. Многим авторам не хватает статистических знаний, что может поставить под угрозу здравоохранение. Цель состояла в том, чтобы использовать искусственный интеллект в качестве статистического метода для оценки потенциального влияния Самофиксирующихся сетчатых имплантатов Adhesix™, Hertra™ и Lintex™ на результаты лечения пациентов с паховой грыжей, перенесших открытую пластику паховой грыжи Лихтенштейн. *Материалы и методы.* Мы выполнили 120 процедур паховой герниопластики по Лихтенштейну, у трех равномерно распределенных групп пациентов (n = 40) с использованием сетчатых имплантатов Adhesix™, Hertra™ и Lintex™. Параметрами для сравнения были продолжительность процедуры, продолжительность пребывания в больнице, осложнения в послеоперационном периоде, возникшие во время краткого наблюдения. *Результаты и обсуждение.* Пациенты первой группы были госпитализированы на более короткие сроки, чем пациенты второй и третьей групп (группа А — 4,9 дня в сутки, группа В-4,9,5 дня в сутки и группа С-4,95 дня в сутки), без статистически значимых различий. У пациентов из первой группы время процедуры значительно сокращается, за ними следуют пациенты из второй и третьей групп (27,8 мин, 31,4 мин и 38,9 мин соответственно). В отличие от третьей группы, в которую вошли 3 пациента с послеоперационным дискомфортом и 1 с образованием послеоперационной серомы, послеоперационное пребывание в стационаре первой и второй групп протекало без осложнений. В отличие от двух пациентов третьей группы, у которых наблюдалась миграция сетки и рецидив грыжи, пациенты первой и второй групп не испытывали осложнений в течение короткого периода наблюдения. *Выводы.* По сравнению с сетчатыми имплантатами Lintex™, время операции при использовании Adhesix™ и Hertra™ значительно сокращается без послеоперационных осложнений или рецидива грыжи.

**Ключевые слова:** грыжа, сетчатые имплантаты, полипропилен, клей, искусственный интеллект

**Информация о финансировании:** Авторы не получали финансовой поддержки для проведения исследований, и публикации этой статьи.

**Заявление о конфликте интересов.** Авторы заявляют об отсутствии конфликта интересов.

**Вклад авторов.** М.Ш.Ф. Мекхаеэль, С.М.А. Салем — концепция и дизайн исследования; А.В. Протасов — редактирование рукописи. Все авторы внесли значительный вклад в разработку концепции, проведение исследования и подготовку статьи, ознакомились с окончательной версией и одобрили ее перед публикацией.

**Этическое утверждение.** Исследование одобрено комиссией по биоэтике ФГБНУ НИИ морфологии человека (Протокол № 3, от 01.02.2019).

**Благодарности.** Мы выражаем нашу глубокую благодарность медицинскому персоналу клинической больницы № 85 Федерального медико-биологического агентства (ФМБА), Москва, Российская Федерация, особенно медсестрам и ординаторам отделения клинической анатомии и оперативной хирургии, которые помогли нам завершить эту исследовательскую работу. Мы также выражаем благодарность пациенту, который согласился на то, чтобы его случай был рассмотрен и опубликован.

**Информационное согласие на публикацию.** Пациенты предоставили добровольное информированное согласие на обработку персональных данных и публикацию.

Поступила 04.06.2025 Принята 01.07.2025.

**Для цитирования:** Protasov A.V., Mekhaeel M.Sh.F., Salem S.M.A. Employing seamless mesh implants during Lichtenstein hernia repair with the use of insights enabled by artificial intelligence // Вестник Российского университета дружбы народов. Серия: Медицина. 2026. Т. 30. № 1. С. 55–65. doi: 10.22363/2313-0245-2026-30-1-55-65. EDN: CYQPQV

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