https://doi.org/10.25207/1608-6228-2022-29-5-94-107

COMPARATIVE EVALUATION OF BIOMECHANICAL CHARACTERISTICS DEFINING ACELLULAR DERMAL MATRIX FOR HERNIOPLASTY

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ABSTRACT

Background. With the introduction of synthetic mesh implants into clinical practice, the recurrence rate of postoperative ventral hernias has been significantly reduced. However, the extensive use of synthetic implants gives rise to specific complications. Thus, it is relevant to develop biological implants that are based on highly purified decellularized collagen matrix of xenogeneic origin as, unlike synthetic analogs, they have a biological origin and biodegrade naturally, gradually being replaced with newly formed connective tissue. The use of biological implants reduces the risk of complications.

Objectives. To comparatively evaluate the biomechanical characteristics of acellular dermal matrix obtained via detergent-enzymatic decellularization and commercially distributed Permacol™ matrix.

Methods. The ADM was created using native skin samples from a 4-month-old Landrace pig, with the dermis treated via the detergent-enzymatic method. In order to comparatively evaluate the mechanical properties of the acellular dermal matrix, the biological samples were divided into 2 groups, each containing 15 samples. The first group was comprised of acellular dermal matrix samples, while the second group included samples of native porcine dermis. The control group consisted of samples collected from the Permacol™ Surgical Implant, a xenograft for hernioplasty approved for use in the Russian Federation (Covidien, France). All samples were tested wet by means of an Instron 1122 Universal Testing Instrument. The obtained results were statistically processed using MedCalc Statistical Software (Belgium).

Results. In the present study, porcine dermis was treated using the detergent-enzymatic method to produce ADM. A routine histological examination confirmed complete decellularization, as well as showing that the native structure of the dermis remained intact during its treatment. The mechanical characteristics of the xenogeneic ADM were determined: tensile strength — 9.1 ± 0.6 MPa (910 N/cm^2); elongation at break — 21.1 ± 2.3%; elastic modulus — 50.0 ± 1.6 MPa. These characteristics largely corresponded to the strength characteristics of native porcine dermis far exceeding the necessary physiological parameters. The control sample (Permacol™) was tested in two directions: longitudinal and transverse. In the longitudinal direction, the sample exhibited high mechanical characteristics: strength — 12.0 ± 1.7 MPa, elongation at break — 29.7 ± 2.4%, stiffness modulus — 47.2 ± 6.5 MPa. Conversely, 1.5–2 times lower values were observed in the transverse direction.

Conclusion. The xenogeneic biological implant developed in the form of ADM is characterized by good plasticity, tensile strength, tensibility, and elasticity, which allows it to be used as a biological implant in the repair of abdominal wall hernias of any size and shape.

Keywords: hernioplasty, acellular dermal matrix, ventral hernia, biological implant, abdominal wall reconstruction, surgical materials

Conflict of interest: the authors declare no conflict of interest.

For citation: Melkonian K.I., Popandopulo K.I., Bazlov S.B., Rusinova T.V., Moskalyuk O.A., Bykov I.M. Comparative Evaluation of Biomechanical Characteristics Defining Acellular Dermal Matrix for Hernioplasty. *Kuban Scientific Medical Bulletin*. 2022; 29(5): 94–107 (In Russ., English abstract). https://doi.org/10.25207/1608-6228-2022-29-5-94-107

Received: 01.03.2022
Received after revision: 27.06.2022
Accepted: 12.08.2022

СРАВНИТЕЛЬНАЯ ОЦЕНКА БИОМЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК АЦЕЛЛЮЛЯРНОГО ДЕРМАЛЬНОГО МАТРИКСА ДЛЯ ГЕРНИОПЛАСТИКИ

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АННОТАЦИЯ

Введение. С внедрением в клиническую практику сетчатых синтетических эндопротезов частоту рецидивов послеоперационных вентральных грыж удалось значительно уменьшить. Широкое применение синтетических имплантов привело к развитию специфических осложнений. Актуальность разработки биологических эндопротезов, основу которых составляет глубоко очищенный децеллюляризованный коллагеновый матрикс ксеногенного происхождения, обусловлена тем, что, в отличие от синтетических аналогов, они имеют биологическую природу, биодеградируют естественным путем, постепенно замещаясь на новообразованную соединительную ткань. Применение биопротезов уменьшает риски осложнений.

Цель исследования — провести сравнительную оценку биомеханических характеристик полученного ацеллюлярного дермального матрикса, полученного методом детергентно-энзиматической децеллюляризации, и коммерческого матрикса Permacol™.

Методы. Для создания ацеллюлярного дермального матрикса (АДМ) были использованы образцы нативной кожи поросенка породы Ландрас возрастом 4 мес. Обработку дермы проводили детергентно-энзиматическим способом. Для сравнительной оценки механических свойств ацеллюлярного дермального матрикса биологические образцы были разделены на 2 группы по 15 образцов в каждой. В первую вошли образцы ацеллюлярного дермального матрикса, во вторую группу вошли нативные образцы свиной дермы, не прошедшие обработку. Контрольную группу составили образцы разрешенного к применению в Российской Федерации ксенотрансплантата для герниопластики Permacol™ Surgical Implant (Covidien, Франция). Все образцы исследовались во влажном состоянии с использованием универсальной разрывной установки Instron 1122. Статистическую обработку результатов исследования выполняли с помощью программы MedCalc Statistical Software (Бельгия).

Результаты. В настоящем исследовании в результате обработки свиной дермы детергентно-энзиматическим методом был получен ацеллюлярный дермальный матрикс. Рутинное гистологическое исследование подтвердило удаление всех клеточных элементов, при этом было доказано, что нативная структура дермы при ее обработке сохранилась. В дальнейшем были определены механические характеристики ксеногенного ацеллюлярного дермального матрикса. Его прочность на разрыв составляла 9,1 ± 0,6 МПа (910 Н/см^2), удлинения при разрыве — 21,1 ± 2,3%, а модуль упругости — 50,0 ± 1,6 МПа. Эти характеристики во многом соответствовали прочностным показателям нативной свиной дермы и намного превышали физиологически необходимые параметры. Контрольный образец Permacol™ был испытан в двух направлениях (продольном и поперечном). В продольном направлении образец имел более высокие механические характеристики: прочность — 12,0 ± 1,7 МПа, удлинение при разрыве — 29,7 ± 2,4%, модуль жесткости — 47,2 ± 6,5 МПа. В поперечном направлении все показатели были в 1,5–2 раза ниже.

Заключение. Разработанный ксеногенный биологический эндопротез в виде ацеллюлярного дермального матрикса обладает хорошими показателями пластичности, прочности на разрыв, растяжимости и упругости, что позволяет использовать его в качестве биологического эндопротеза при пластике грыжевых дефектов брюшной стенки любого размера и формы.

Ключевые слова: герниопластика, ацеллюлярный дермальный матрикс, вентральная грыжа, биологический имплантат, реконструкция брюшной стенки, хирургические материалы

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Для цитирования: Мелконян К.И., Попандопуло К.И., Базлов С.Б., Русинова Т.В., Москалюк О.А., Быков И.М. Сравнительная оценка биомеханических характеристик ацеллюлярного дермального матрикса для герниопластики. *Кубанский научный медицинский вестник*. 2022; 29(5): 94–107. https://doi.org/10.25207/1608-6228-2022-29-5-94-107

Получена: 01.03.2022
Получена после доработки: 27.06.2022
Принята к публикации: 12.08.2022

INTRODUCTION

Implant selection for hernioplasty performed to treat ventral hernias maintains its relevance nowadays [1]. With the introduction of synthetic mesh implants into clinical practice, the recurrence rate of postoperative ventral hernia has been significantly reduced[1] [1–11]. However, the widespread use of synthetic implants gives rise to the following specific complications: implant migration to the abdominal cavity; adhesive intestinal obstruction and intestinal fistula formation with adhesion between the intestine and the implant; seroma formation or implant infection; implant rejection or rupture followed by hernia recurrence [10, 11]. In some cases, the postoperative life quality of patients can be impaired by the chronic pain syndrome in the area of the postoperative scar, paresthesia, foreign body sensation, as well as the restricted mobility of the anterior abdominal wall [11, 12]. Recent years have seen an active development of biological implants that are based on highly purified decellularized antigen-free collagen matrix of xenogeneic origin [13, 14]. Unlike their synthetic counterparts, they are of biological origin and biodegrade naturally, gradually being replaced with newly formed connective tissue. The use of biological implants reduces the risks of seromas, fistulas, implant rippling, as well as the formation of coarse fibrous connective tissue in the area of repair [13–16].

Acellular porcine xenografts have been studied most extensively to date, an example of which is Surgisis® (Cook Biomedical, Bloomington, IN, USA) derived from porcine small intestinal submucosa. Several porcine skin derivatives treated via different methods are also available as grafts: Permacol™ (Covidien, Ireland) and Collamend® (Davol Inc., UK). Heterografts derived from the pericardium or fetal dermis of bovine donors include Tutopatch® (Tutogen, USA) [6].

[1] Belokonev V.I., Gogiya B.Sh., Gorskiy V.A., Ermakov N.A., Zhdanovskiy V.V., Ivanov I.S., Ivanov S.V., Il'chenko F.N., Kabanov E.N., Kovaleva Z.V., Lebedev N.N., Matveev N.L., Mishustin A.M., Narezkin D.V., Parshikov V.V., Presnov K.S., Protasov A.V., Pushkin S.Yu., Rybachkov V.V., Rutenburg G.M., Samartsev V.A., Tevyashov A.V., Kharitonov S.V., Cherepanin A.I., Chernykh A.V., Shestakov A.L., Shikhmetov A.N., Ettinger A.P., Yurasov A.V., *Inguinal and Postoperative Hernias. National Clinical Guidelines on Herniology* [in Russian], Moscow (2018).

However, the production of such biological implants involves a complex process, requiring the use of special equipment, which significantly increases their cost. Also, the need for the dehydration of some types of implants complicates their practical application. Another serious issue consists in the insufficient strength of biological implants, which increases the risk of hernia recurrence [17,18]. In this connection, it is necessary to create and evaluate new non-immunogenic biological implants for hernioplasty that are characterized by biodegradability and high strength. Thus, acellular dermal matrix was derived from porcine xenodermis for abdominal wall ventral hernioplasty at the Central Research Laboratory of the Kuban State Medical University of the Ministry of Healthcare of the Russian Federation (Russian Patent RU 2768156 C1; registration date: 05/31/2021; patent application No. 2022109499/20(019863) as of 04/08/2022).

The paper **aims** to comparatively evaluate the biomechanical characteristics of the obtained acellular dermal matrix (ADM).

METHODS

Experimental animals

In order to obtain biological samples (sampling of dermis for ADM production), three 6-month-old Landrace gilts weighing 38.8 kg that had undergone quarantine for at least 14 days at the vivarium laboratory of the Education Department of Kuban State Medical University (KubSMU) were selected from the experimental and educational farm *Kuban* of the Kuban State Agrarian University named after I. T. Trubilin (KubSAU).

Accommodation and maintenance of animals

The animals were kept in the vivarium under standard conditions: 12 hours of light per day, free access to water and food, standard food and water ration, and temperature range of 18–25 °C. The animals were kept and the experiments were conducted in accordance with the following regulatory documents: Order of the Ministry of Healthcare of the Russian Federation No. 199n (as of April 1, 2016) *On Approval of the Rules of Good Laboratory Practice*, GOST 33215-2014 *Guidelines for Accommodation and Care of Animals. Environment, Housing and Management*, *Directive 2010/63/EU of the European Parliament and of the Council* of September 22, 2010 on the protection of animals, and *European Convention for the Protection of Vertebrate Animals Used for Experimental and other Scientific Purposes* (ETS 123, Strasbourg, 1986). The animals were fed according to daily norms (Order of the rector the KubSMU No. 527 as of 07/09/2015 *On the Formation of a Commission for Determining the Feeding Norms for Laboratory Animals*).

Study design

Thirty samples of porcine dermis were examined in an uncontrolled (randomized) experimental clinical study as models of nonimmunogenic biological implants for hernioplasty. A Permacol™ Surgical Implant (Covidien, France) for hernia repair approved for use in the Russian Federation was adopted as a reference. The design of the study is presented in Figure 1.

Sample size

In order to comparatively evaluate the mechanical properties of the ADM, all biological samples were divided into two groups, each containing 15 samples. The first group was comprised of ADM samples (decellularized porcine dermis treated via the detergent-enzymatic method), while the second group included samples of untreated native porcine dermis. The control group consisted of samples (n=15) collected from the Permacol™ Surgical Implant, a xenograft for hernioplasty.

Inclusion/exclusion criteria

Inclusion criteria

Dermal samples were collected from healthy animals showing no visible skin lesions.

Exclusion criteria

Damage to dermal samples during the decellularization procedure.

Randomization

The dermal samples were distributed prior to the decellularization procedure using a closed envelope method.

Data anonymity assurance

In the study, data was not anonymized.

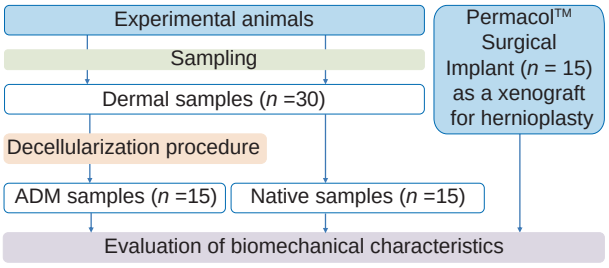

Fig. 1. Schematic diagram of the research design.
Рис. 1. Блок-схема дизайна исследования.

Resulting indicators (outcomes of the study)

A study comparing the strength characteristics of ADM samples obtained using an original procedure and the Permacol™ Surgical Implant as a xenograft for hernioplasty.

Experimental procedures

The experiments (dermal sampling) were performed following euthanasia of the animal in accordance with the regulatory documents: Order of the Ministry of Healthcare of the Russian Federation No. 199n (as of April 1, 2016) *On Approval of the Rules of Good Laboratory Practice*, GOST 33215-2014 *Guidelines for Accommodation and Care of Animals. Environment, Housing and Management*, *Directive 2010/63/EU of the European Parliament and of the Council* on the protection of animals, and *European Convention for the Protection of Vertebrate Animals Used for Experimental and other Scientific Purposes* (ETS 123, Strasbourg, 1986). The animals were euthanized using a lethal dose of Zoletil 100 (active ingredients — tiletamine hydrochloride and zolazepam hydrochloride).

Porcine dermis was sampled using a disk dermatome (disk knife diameter — 100 mm). The decellularization procedure was performed using the following solutions and detergents: trypsin-versene solution (Biolot, Russia), 1% Triton X-100 (Sigma-Aldrich, USA), 4% sodium deoxycholate (Sigma-Aldrich, USA), porcine pancreatic DNase I (EC 3.1.22.1, Sigma-Aldrich, USA), 2000 U/200 ml of phosphate buffer with calcium and magnesium. The obtained ADM was subjected to a histological examination: hematoxylin-eosin staining.

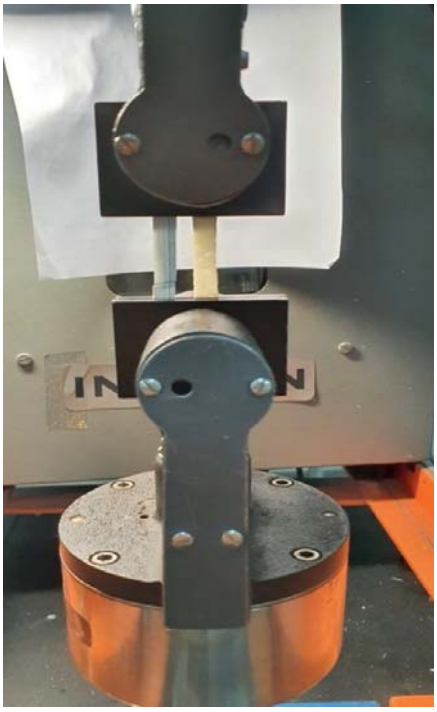

Fig. 2. Study of biomechanical properties exhibited by the ADM using the Instron 1122 instrument.
Рис. 2. Исследование биомеханических свойств АДМ на установке Instron 1122.

All samples (reference sample length of 30 mm for both groups) were examined wet using an Instron 1122 Universal Testing Instrument (Fig. 2) at 23 ± 1°C, a pressure of 762 ± 2 mmHg, a humidity of 45%, and a tensile rate of 20 mm/min.

The obtained stress-strain diagrams were used to determine the main mechanical characteristics of the samples:

$$\sigma = \frac{P}{F_o}, \quad (1)$$

where σ — strength, MPa; P — breaking load, N/cm^2; F_o — cross-sectional area, mm;

$$\varepsilon = \frac{\Delta l}{l_0}, \quad (2)$$

where ε — relative strain at break, %; Δ*l* — absolute elongation, mm; l_0 — initial (reference) length, m;

$$E_o = \frac{\Delta\sigma}{\Delta\varepsilon}, \quad (3)$$

where E_o — initial modulus of elasticity, MPa, Δσ — change in strength at a given section of the stress-strain diagram, MPa, Δε — change in the relative strain at break at a given section of the stress-strain diagram, %.

Care and monitoring of the animals

No care and monitoring of the animals were provided.

Statistical methods

The study results were statistically processed using MedCalc Statistical Software (Belgium). The sample distribution was assessed using the Shapiro–Wilk test. Since all variation series showed a normal distribution, the results are presented as M±SD, where M is the arithmetic mean and SD is the standard deviation. The Student's *t*-test was employed to compare absolute values in the groups as the samples were of the same size and demonstrated the same variance, with differences considered significant at $p < 0.05$. When constructing stress-strain diagrams of biomaterial samples in the Origin 8.5.1 program (OriginLab Corporation), the arithmetic mean of the obtained values was used.

RESULTS

Due to the detergent-enzymatic treatment of native dermis samples, the resulting ADM was white

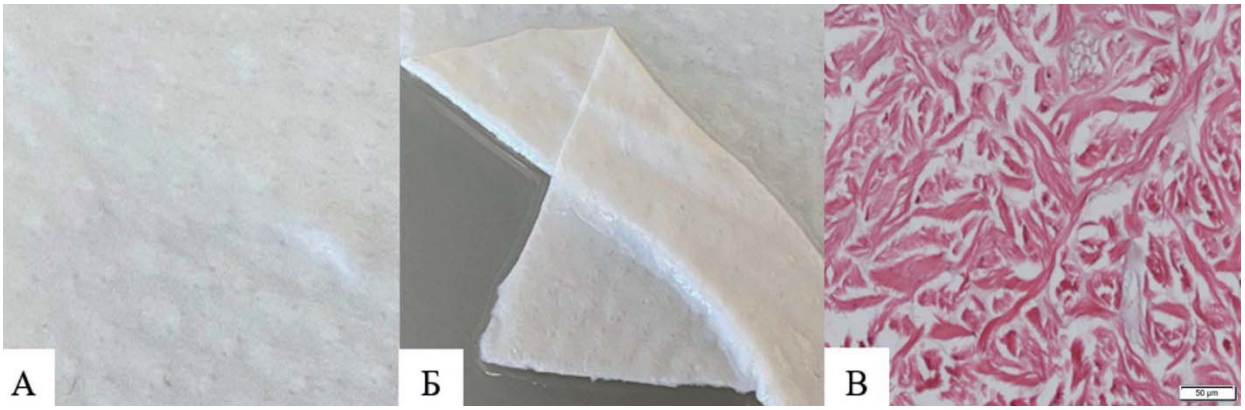

Fig. 3. Acellular dermal matrix: A — general view; Б — plasticity; B — hematoxylin-eosin staining (x200 magnification)
Key: 1) A — A; 2) Б — B; 3) B — C
Рис. 3. Ацеллюлярный дермальный матрикс: А — общий вид; Б — пластичность; В — гистологическая окраска гематоксилин-эозином (ув. ×200).

in color and had a smooth and microporous surface (Fig. 3A). The obtained ADM exhibited greater plasticity as compared to heavy polypropylene mesh implants and Permacol™ Surgical Implant samples (Covidien, France). The plastic properties of the ADM allow it to be optimally adjusted to the shape and size of hernia defects (Fig. 3Б). A routine histological examination confirmed complete decellularization, as well as showing that the native structure of the dermis remained intact during its treatment (Fig. 3B).

Data obtained from the tensile tests of available samples are shown in Table 1. These data were used to construct the stress-strain diagrams of biomaterial samples (Fig. 4) and determine their main physical properties (Table 2).

It follows from the presented data that the native porcine dermis has a strength of 11.62 ± 2.80 MPa, a strain at break of 25.41 ± 4.20%, and an elastic modulus of 56.13 ± 9.19 MPa. Taking the measurement error into account, the decellularized porcine dermis treated via the detergent-enzymatic method (Group 1 samples) exhibits mechanical properties that are close to the original sample: $\sigma = 9.13 \pm 0.63$ MPa, $\varepsilon = 21.12 \pm 2.30\%$, and $E_o = 50.01 \pm 1.58$ MPa.

In terms of mechanical characteristics, the Group 2 samples are most similar to the control sample tested in the longitudinal direction, while the Group 1 samples resemble the control sample examined in the transverse direction.

The control sample (Permacol™) was tested in two directions: longitudinal and transverse. In the longitudinal direction, the sample exhibited high mechanical characteristics: strength — 12.02 ± 1.74 MPa, elongation at break — 29.70 ± 2.44%, and stiffness modulus — 47.20 ± 6.53 MPa. Conversely, lower values were observed in the transverse direction ($p < 0.05$).

DISCUSSION

Interpretation /scientific merit

The present study revealed that the xenogeneic ADM designed to be used as an implant for hernioplasty exhibits high strength, which is comparable to or even higher than that of its synthetic counterparts. Its characteristics are as follows: strength — 9.13 ± 0.63 MPa (910 N/cm^2); relative strain at break — 21.12 ± 2.30%; initial modulus of elasticity — 50.01 ± 1.58 MPa. These characteristics largely correspond to the strength characteristics of native porcine dermis, far exceeding the physiologically required parameters, which should be taken into account during hernioplasty. The best results were obtained when testing decellularized dermis treated via the detergent-enzymatic method.

The Permacol™ Surgical Implant control sample also exhibits high strength characteristics; however, these characteristics differ significantly under the longitudinal and transverse loading. Under transverse loading, they decrease by 1.5–2 times, which necessitates the choice of the correct implant position. In addition, the ADM exhibits significantly more pronounced plastic properties as compared to the Permacol™, which gives it an advantage in the repair of complex-shaped hernia defects, as well as minimizing the formation of a coarse connective tissue capsule around the implant.

Table 1. Tensile properties of biological samples
Таблица 1. Механические показатели при растяжении биологических образцов

ADM		Native porcine dermis		Permacol™ (longitudinal direction)		Permacol™ (transverse direction)	
ε, %	σ, MPa	ε, %	σ, MPa	ε, %	σ, MPa	ε, %	σ, MPa
0	0	0	0	0	0	0	0
1.33 ± 0.12	0.69 ± 0.08	2.33 ± 0.66	1.67 ± 0.84	2.00 ± 0.58	1.00 ± 0.09	1.17 ± 0.49	0.50 ± 0.07
2.66 ± 0.57	1.39 ± 0.34	4.83 ± 0.25	3.33 ± 1.12	4.00 ± 0.13	2.00 ± 0.37	2.33 ± 0.64	1.00 ± 0.11
4.00 ± 1.09	2.08 ± 0.96	7.33 ± 0.98	5.00 ± 1.08	5.99 ± 0.29	3.00 ± 0.38	3.66 ± 0.28	1.50 ± 0.86
5.33 ± 1.11	2.78 ± 0.14	9.66 ± 2.01	6.67 ± 0.17	8.33 ± 1.12	4.00 ± 1.12	5.16 ± 0.06	2.00 ± 0.01
6.66 ± 1.51	3.47 ± 1.52	12.15 ± 0.54	8.33 ± 0.66	10.32 ± 0.44	5.00 ± 1.02	6.49 ± 0.17	2.50 ± 0.44
7.99 ± 0.46	4.17 ± 0.05	14.65 ± 0.55	10.00 ± 0.14	11.99 ± 0.69	6.00 ± 0.99	7.66 ± 0.56	3.00 ± 0.52
9.66 ± 1.04	4.86 ± 0.02	17.32 ± 0.16	11.67 ± 1.88	13.99 ± 0.87	7.00 ± 0.15	8.99 ± 0.46	3.50 ± 1.08
10.66 ± 1.00	5.56 ± 1.42	20.31 ± 0.74	12.00 ± 0.12	15.65 ± 0.64	8.00 ± 0.16	9.99 ± 0.33	4.00 ± 1.11
11.99 ± 0.44	6.25 ± 0.98	24.31 ± 1.33	12.67 ± 0.18	17.32 ± 1.55	9.00 ± 0.27	10.99 ± 1.28	4.50 ± 0.45
13.65 ± 0.59	6.94 ± 1.14	–	–	19.31 ± 1.08	10.00 ± 0.46	12.32 ± 0.34	5.00 ± 0.56
14.65 ± 1.71	7.64 ± 0.14	–	–	22.98 ± 1.10	11.00 ± 0.59	13.65 ± 0.44	5.50 ± 0.89
16.32 ± 0.51	8.33 ± 0.22	–	–	28.97 ± 0.12	12.00 ± 1.14	16.48 ± 0.16	6.10 ± 1.46
17.98 ± 0.04	9.03 ± 0.85	–	–	29.64 ± 1.25	12.00 ± 1.23	–	–
19.98 ± 1.47	9.31 ± 1.62	–	–	–	–	–	–

Table 2. Main mechanical properties of biomaterials, M ± SD
Таблица 2. Основные механические свойства биоматериалов, M ± SD

Sample	ε, %	σ, MPa	E_0, MPa
ADM	21.12 ± 2.30	9.13 ± 0.63	50.01 ± 1.58
Native porcine dermis	25.41 ± 4.20	11.62 ± 2.80	56.13 ± 9.19
Permacol™ (longitudinal direction)	29.70 ± 2.44	12.02 ± 1.74	47.20 ± 6.53
Permacol™ (transverse direction)	17.52 ± 2.63*#+	6.17 ± 0.62*#+	28.37 ± 6.14*#+

*Note: * — p<0.05 vs. ADM, # — p<0.05 vs. native pig dermis, + — p < 0.05 vs. longitudinally directed Permacol™; АДМ — acellular dermal matrix.*
*Примечание: * — p < 0,05 по сравнению с АДМ, # — p < 0,05 по сравнению с нативной дермой свиньи, + — p < 0,05 по сравнению с продольно ориентированным Permacol™; АДМ — ацеллюлярный дермальный матрикс.*

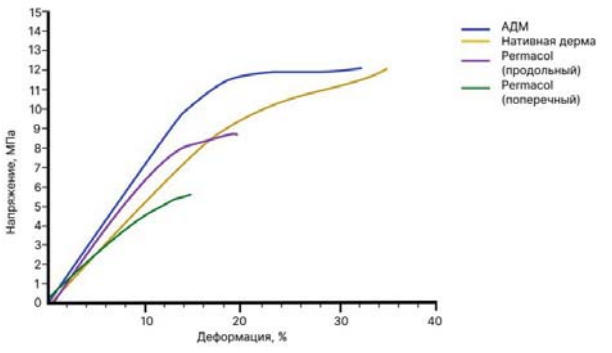

Fig. 4. Stress-train diagrams of biomaterial samples. Key: 1) АДМ — ADM; 2) Нативная дерма — Native dermis; 3) Permacol (продольный) — Permacol (longitudinal direction); 4) Permacol (поперечный) — Permacol (transverse direction); 5) Напряжение, МПа — Stress, MPa; 6) Деформация, % — Strain, %
Рис. 4. Диаграммы растяжения образцов биоматериалов.

Research limitations

Not identified.

Generalizability/extrapolation

Ventral hernia repair is one of the most common surgical procedures, with the strength of implants for hernioplasty adopted as one of the most important criteria for their selection. Most cases involve the use of tension-free hernioplasty employing highly polymeric implants made of polyethylene, polypropylene, polytetrafluoroethylene (PTFE), ivalon, nylon, etc. [1–11]. Synthetic materials are characterized by commercial availability, high strength, inability to biodegrade, and biological inertness.

The issue regarding the required strength of implants is currently understudied. It is known that the maximum abdominal pressure resulting from coughing or sneezing can reach 150 mmHg or 0.02 MPa. The strength of an implant is considered sufficient

at a breaking load of 16 N/cm^2 (0.16 MPa) for small-sized hernias and 32 N/cm^2 (0.32 MPa) for large hernias[2] [18,19].

The conducted studies revealed that the strength of synthetic implants significantly exceeds that which is physiologically required (36–56 N/cm^2 or 0.36–0.56 MPa)[2] [18,19]. The tensile strength amounts to 137 N/cm^2 (1.4 MPa) for Prolene (Ethicon, Johnson & Johnson Medical Ltd., Germany), 118 N/cm^2 (1.2 MPa) for Surgipro™ (Covidien, France), 109 N/cm^2 (1.1 MPa) for Premilene® (B. Braun, Germany), and 96.2 N/cm^2 (0.96 MPa) for Esfil® (Lintex, Russia). Nevertheless, it is widely believed that the use of lighter implants in case of large hernias can lead to the implant rupturing in the middle and a higher recurrence rate [20]. Upon the capsule formation, the strength of the implant having a connective tissue component increases significantly, which can exceed the initial values by 2.6 to 5 times. This process is accompanied by a 2-fold increase in stiffness, a decrease in tensibility and elongation at break, as well as a size reduction of the implant by up to 26.7% [21], which may be the cause of hernia recurrence. The use of heavy large mesh implants that extend beyond the borders of the hernia defect up to 5 cm increases the invasiveness of the procedure while causing complications in the form of seroma, discomfort, and the restricted mobility of the anterior abdominal wall in almost half of the patients [22].

Biological implants developed to date are devoid of these drawbacks, as well as exhibiting minimal inflammatory reactions of adjacent tissues, biocompatibility, and biodegradability. The primary problem associated with the use of biological implants lies in their insufficient strength[2] [10, 12].

Thus, the developed acellular xenogeneic dermal matrix exhibits the necessary physical characteristics for it to be used as a surgical implant in the treatment of anterior abdominal wall hernias in the experiment. Further, it is planned to conduct a comparative experimental study into the biodegradation and biointegration of the developed matrix and its commercial counterpart. *In vitro* calcification and biodegradation tests will be performed; in addition, immunohistochemistry will be used to evaluate the response of the recipient body (experimental animals) to the use of various biological materials during hernioplasty. The achievement of project objectives will ensure significant progress in understanding how the extracellular matrix components of xenogeneic implants participate in renewing the histoarchitecture of human tissues in the process of their repair.

CONCLUSION

The developed xenogeneic biological implant in the form of ADM exhibits good plasticity, tensile strength, tensibility, and elasticity in comparison with synthetic allografts, as well as available commercial counterparts of biological implants. Thus, it can be used as a biological implant in the repair of abdominal wall hernias of any size and shape. Provided no pronounced tissue reactions to the implant or cytotoxicity effects are observed and the immunogenicity is low, the ADM can become a competitive commercial biomaterial for hernioplasty in the domestic and world market.

Protocol registration

The study design was prepared prior to the study and approved by the Independent Committee for Ethics of the Kuban State Medical University (Ministry of Healthcare of the Russian Federation).

Data access

Data on the conducted study can be freely accessed in machine-readable form to be used and republished without any limitations.

COMPLIANCE WITH ETHICAL STANDARDS

The study protocol was approved by the Independent Committee for Ethics (Minutes No. 102 as of October 1, 2021) of the Kuban State Medical University (Mitrofana Sedina str., 4, Krasnodar, Russia). The animal welfare was kept in accordance with the principles of the Declaration of Helsinki on Humane Treatment of Animals, Directive 2010/63/EU of the European Parliament and of the Council of September 22, 2010 on the protection of animals used for scientific purposes, GOST 33044–2014 *Principles of Good Laboratory Practice* approved by Order No. 1700-ST (November 20, 2014) of the Federal Agency for Technical Regulation and Metrology.

СООТВЕТСТВИЕ ПРИНЦИПАМ ЭТИКИ

Протокол исследования одобрен Независимым Этическим комитетом федерального государственного бюджетного образовательного учреждения высшего образования «Кубанский государственный медицинский университет» Министерства здравоохранения Российской Федерации (ул. им. Митрофана Седина, д. 4, г. Краснодар, Россия) протокол № 102 от 01.10.21 г. Условия содержания животных и работы с ними соответствовали принципам Хельсинкской декларации о гуманном отношении к животным, директиве Европейского парламента и Совета

[2] Zhukovskiy V.A. Polymeric implants for hernioplasty: current trends and development approaches. *Grekov's Bulletin of Surgery*. 2011; 2(170): 102–105.

Европейского союза 2010/63/ЕС от 22 сентября 2010 г. «О защите животных, используемых для научных целей», ГОСТу 33044–2014 «Принципы надлежащей лабораторной практики», утвержденному Приказом Федерального агентства по техническому регулированию и метрологии № 1700-СТ от 20 ноября 2014 г.

FUNDING

The study was supported by grant No. 22-25-00199 from the Russian Science Foundation.

ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование выполнено за счет гранта Российского научного фонда № 22-25-00199.

REFERENCES

1. Feoktistov Ya.E., Nikol'skiy V.I., Titova E.V., Feoktistova E.G., Ogorodnik E.V. Comparative evaluation of the clinical and economic efficiency of intra-abdominal hernioplasty with a combined endoprosthesis (from biological and synthetic materials) and a polypropylene mesh with anti-adhesive coating. *University Proceedings. Volga Region. Medical Sciences*. 2019; 3(51): 54–65 (In Russ., English abstract). DOI: 10.21685/2072-3032-2019-3-5
2. Demin N.A., Achkasov E.E., Abdurashidova M.R., Kalachev O.A., Ivanov G.V. Surgeon's view on feature of rehabilitation in patients with large incisional ventral hernia after open retro-rectus hernioplasty. *Clinical and Experimental Surgery. Petrovsky Journal*. 2022; 10(2): 88–95 (In Russ., English abstract). DOI: 10.33029/2308-1198-2022-10-2-88-95
3. Kulchenko N.G. Inguinal hernia repair and male health. *Research and Practical Medicine Journal (Issled. prakt. med.)*. 2019; 6(3): 65–73 (In Russ., English abstract). DOI: 10.17709/2409-2231-2019-6-3-6
4. Kazakova V.V., Yartsev P.A., Blagovestnov D.A., Kirsanov I.I. Abdominal wall prosthetic plastic in treatment of patients with medium abdominal hernia (literature review). *Journal of New Medical Technologies*. 2021; 15(5): 22–31 (In Russ., English abstract). DOI: 10.24412/2075-4094-2021-5-1-3
5. HerniaSurge Group. International guidelines for groin hernia management. *Hernia*. 2018; 22(1): 1–165. DOI: 10.1007/s10029-017-1668-x
6. Faylona J.M. Evolution of ventral hernia repair. *Asian. J. Endosc. Surg*. 2017; 10(3): 252–258. DOI: 10.1111/ases.12392
7. Attaar M., Forester B., Chirayil S., Su B., Wong H.J., Kuchta K., Linn J., Denham W., Haggerty S., Ujiki M.B. Mesh in Elective Hernia Repair: 10-Year Experience with over 6,000 Patients. *J. Am. Coll. Surg*. 2021; 233(1): 51–62. DOI: 10.1016/j.jamcollsurg.2021.03.006
8. Gossetti F., Zuegel N., Giordano P., Pullan R., Schuld J., Delrio P., Montorsi M., van Kerschaver O., Lemaitre J., Griffiths B., D'Amore L. A Biologic Surgical Implant in Complex Abdominal Wall Repair: 3-Year Follow-Up Results of a Multicentric Prospective Study. *Med. Devices. (Auckl)*. 2021; 14: 257–264. DOI: 10.2147/MDER.S297897
9. Melnik I., Mnouskin Y., Verdiger Kurzbart E., Yoffe B. Evaluation of a porcine dermal collagen (permacol) implant for abdominal wall reconstruction in a pediatric multitrauma patient. *Case. Rep. Emerg. Med*. 2014; 2014: 585723. DOI: 10.1155/2014/585723
10. Murray J.A.B. Técnica quirúrgica para reparar la diástasis de rectos asociada a hernia umbilical. diez años de experiencia. *Sociedad Hispanoamericana de Hernia*. 2017; 5(2): 52–56. DOI: 10.20960/rhh.34
11. Klosterhalfen B., Junge K., Klinge U. The lightweight and large porous mesh concept for hernia repair. *Expert. Rev. Med. Devices*. 2005; 2(1): 103–117. DOI: 10.1586/17434440.2.1.103
12. Erkent M., Şahiner İ.T., Kendirci M., Topçu R. İnsizyonel Herni Gelişiminde Risk Faktörlerinin Saptanması. *Hitit. Med. J*. 2019; 1(1): 15–17.
13. Badyrov R.M., Abatov N.T., Tussupbekova M.M., Alberton J.N., Mussabekov I.K. Results after application of the extracellular bovine-derived peritoneum matrix for abdominal wall reconstruction in the long-term experiment. *Science & Healthcare*. 2018; 1: 24–35 (In Russ., English abstract). DOI: 10.34689/SH.2018.20.1.002
14. Madani A., Niculiseanu P., Marini W., Kaneva P.A., Mappin-Kasirer B., Vassiliou M.C., Khwaja K., Fata P., Fried G.M., Feldman L.S. Biologic mesh for repair of ventral hernias in contaminated fields: long-term clinical and patient-reported outcomes. *Surg. Endosc*. 2017; 31(2): 861–871. DOI: 10.1007/s00464-016-5044-1
15. Costa A., Adamo S., Gossetti F., D'Amore L., Ceci F., Negro P., Bruzzone P. Biological Scaffolds for Abdominal Wall Repair: Future in Clinical Application? *Materials (Basel)*. 2019; 12(15): 2375. DOI: 10.3390/ma12152375
16. Gossetti F., Grimaldi M.R., Ceci F., D'Amore L., Negro P. Comment on: Comparative analysis of biologic versus synthetic mesh outcomes in contaminated hernia repairs. *Surgery*. 2017; 161(5): 1467–1468. DOI: 10.1016/j.surg.2016.10.014

17. Baylón K., Rodríguez-Camarillo P., Elías-Zúñiga A., Díaz-Elizondo J.A., Gilkerson R., Lozano K. Past, Present and Future of Surgical Meshes: A Review. *Membranes (Basel)*. 2017; 7(3): 47. DOI: 10.3390/membranes7030047

18. Zhukovsky V.A. Polymer implants for reconstructive surgery. *Scientific electronic journal «INNOVA»*. 2016; 2(3): 51–59 (In Russ., English abstract). DOI: 10.21626/innova/2016.2/05

19. Romanowska M., Okniński T., Pawlak J. Modern Materials Applied in Hernioplasty. *Pol. Przegl. Chir*. 2016; 88(4): 226–231. DOI: 10.1515/pjs-2016-0057

20. Klosterhalfen B., Junge K., Klinge U. The lightweight and large porous mesh concept for hernia repair. *Expert. Rev. Med. Devices*. 2005; 2(1): 103–117. DOI: 10.1586/17434440.2.1.103

21. Nisiewicz M., Hughes T., Plymale M.A., Davenport D.L., Roth J.S. Abdominal wall reconstruction with large polypropylene mesh: is bigger better? *Hernia.* 2019; 23(5): 1003–1008. DOI: 10.1007/s10029-019-02026-3

22. Warren J.A., McGrath S.P., Hale A.L., Ewing J.A., Carbonell A.M. 2nd, Cobb W.S. 4th. Patterns of Recurrence and Mechanisms of Failure after Open Ventral Hernia Repair with Mesh. *Am. Surg*. 2017; 83(11): 1275–1282.

СПИСОК ЛИТЕРАТУРЫ

1. Феоктистов Я.Е., Никольский В.И., Титова Е.В., Феоктистова Е.Г., Огородник Е.В. Сравнительная оценка клинико-экономической эффективности интраабдоминальной герниопластики комбинированным эндопротезом (из биологического и синтетического материала) и полипропиленовой сетки с антиадгезивным покрытием. *Известия высших учебных заведений. Поволжский регион. Медицинские науки*. 2019; 3(51): 54–65. DOI: 10.21685/2072-3032-2019-3-5

2. Демин Н.А., Ачкасов Е.Е., Абдурашидова М.Р., Калачев О.А., Иванов Г.В. Взгляд хирурга на особенности реабилитации пациентов с послеоперационными вентральными грыжами большого размера после открытой герниопластики retrorectus. *Клиническая и экспериментальная хирургия. Журнал имени академика Б.В. Петровского*. 2022; 10(2): 88–95. DOI: 10.33029/2308-1198-2022-10-2-88-95

3. Кульченко Н.Г. Паховая герниопластика и мужское здоровье. *Исследования и практика в медицине*. 2019; 6(3): 65–73. DOI: 10.17709/2409-2231-2019-6-3-6

4. Казакова В.В., Ярцев П.А., Благовестнов Д.А., Кирсанов И.И. Протезирующая пластика брюшной стенки в лечении пациентов со срединными грыжами живота (обзор литературы). *Вестник новых медицинских технологий. Электронное издание*. 2021; 15(5): 22–31. DOI: 10.24412/2075-4094-2021-5-1-3

5. HerniaSurge Group. International guidelines for groin hernia management. *Hernia*. 2018; 22(1): 1–165. DOI: 10.1007/s10029-017-1668-x

6. Faylona J.M. Evolution of ventral hernia repair. *Asian. J. Endosc. Surg*. 2017; 10(3): 252–258. DOI: 10.1111/ases.12392

7. Attaar M., Forester B., Chirayil S., Su B., Wong H.J., Kuchta K., Linn J., Denham W., Haggerty S., Ujiki M.B. Mesh in Elective Hernia Repair: 10-Year Experience with over 6,000 Patients. *J. Am. Coll. Surg*. 2021; 233(1): 51–62. DOI: 10.1016/j.jamcollsurg.2021.03.006

8. Gossetti F., Zuegel N., Giordano P., Pullan R., Schuld J., Delrio P., Montorsi M., van Kerschaver O., Lemaitre J., Griffiths B., D'Amore L. A Biologic Surgical Implant in Complex Abdominal Wall Repair: 3-Year Follow-Up Results of a Multicentric Prospective Study. *Med. Devices. (Auckl)*. 2021; 14: 257–264. DOI: 10.2147/MDER.S297897

9. Melnik I., Mnouskin Y., Verdiger Kurzbart E., Yoffe B. Evaluation of a porcine dermal collagen (permacol) implant for abdominal wall reconstruction in a pediatric multitrauma patient. *Case. Rep. Emerg. Med*. 2014; 2014: 585723. DOI: 10.1155/2014/585723

10. Murray J.A.B. Técnica quirúrgica para reparar la diástasis de rectos asociada a hernia umbilical. diez años de experiencia. *Sociedad Hispanoamericana de Hernia*. 2017; 5(2): 52–56. DOI: 10.20960/rhh.34

11. Klosterhalfen B., Junge K., Klinge U. The lightweight and large porous mesh concept for hernia repair. *Expert. Rev. Med. Devices*. 2005; 2(1): 103–117. DOI: 10.1586/17434440.2.1.103

12. Erkent M., Şahiner İ.T., Kendirci M., Topçu R. İnsizyonel Herni Gelişiminde Risk Faktörlerinin Saptanması. *Hitit. Med. J*. 2019; 1(1): 15–17.

13. Бадыров Р.М., Абатов Н.Т., Тусупбекова М.М., Альбертон И.Н., Мусабеков И.К. Результаты применения внеклеточного матрикса ксенобрюшины для реконструкции передней брюшной стенки в отдаленные сроки эксперимента. *Наука и Здравоохранение*. 2018; 1: 24–35. DOI: 10.34689/SH.2018.20.1.002

14. Madani A., Niculiseanu P., Marini W., Kaneva P.A., Mappin-Kasirer B., Vassiliou M.C., Khwaja K., Fata P., Fried G.M., Feldman L.S. Biologic mesh for repair of ventral hernias in contaminated fields: long-term clinical and patient-reported outcomes. *Surg.*

Endosc. 2017; 31(2): 861–871. DOI: 10.1007/s00464-016-5044-1

15. Costa A., Adamo S., Gossetti F., D'Amore L., Ceci F., Negro P., Bruzzone P. Biological Scaffolds for Abdominal Wall Repair: Future in Clinical Application? *Materials (Basel)*. 2019; 12(15): 2375. DOI: 10.3390/ma12152375
16. Gossetti F., Grimaldi M.R., Ceci F., D'Amore L., Negro P. Comment on: Comparative analysis of biologic versus synthetic mesh outcomes in contaminated hernia repairs. *Surgery*. 2017; 161(5): 1467–1468. DOI: 10.1016/j.surg.2016.10.014
17. Baylón K., Rodríguez-Camarillo P., Elías-Zúñiga A., Díaz-Elizondo J.A., Gilkerson R., Lozano K. Past, Present and Future of Surgical Meshes: A Review. *Membranes (Basel)*. 2017; 7(3): 47. DOI: 10.3390/membranes7030047
18. Жуковский В.А. Полимерные имплантаты для реконструктивной хирургии. *Научный электронный журнал «INNOVA»*. 2016; 2(3): 51–59. DOI: 10.21626/innova/2016.2/05
19. Romanowska M., Okniński T., Pawlak J. Modern Materials Applied in Hernioplasty. *Pol. Przegl. Chir.* 2016; 88(4): 226–231. DOI: 10.1515/pjs-2016-0057
20. Klosterhalfen B., Junge K., Klinge U. The lightweight and large porous mesh concept for hernia repair. *Expert. Rev. Med. Devices*. 2005; 2(1): 103–117. DOI: 10.1586/17434440.2.1.103
21. Nisiewicz M., Hughes T., Plymale M.A., Davenport D.L., Roth J.S. Abdominal wall reconstruction with large polypropylene mesh: is bigger better? *Hernia.* 2019; 23(5): 1003–1008. DOI: 10.1007/s10029-019-02026-3
22. Warren J.A., McGrath S.P., Hale A.L., Ewing J.A., Carbonell A.M. 2nd, Cobb W.S. 4th. Patterns of Recurrence and Mechanisms of Failure after Open Ventral Hernia Repair with Mesh. *Am. Surg*. 2017; 83(11): 1275–1282.

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Conceptualization — concept statement; statement and development of key goals and objectives.

Conducting research — data analysis and interpretation.

Text preparation and editing — drafting of the manuscript and its final version, contribution to the scientific layout.

Approval of the final version of the paper — acceptance of responsibility for all aspects of the work, the integrity of all parts of the paper and its final version.

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Подготовка и редактирование текста — составление черновика рукописи и формирование его окончательного варианта, участие в научном дизайне.

Утверждение окончательного варианта — принятие ответственности за все аспекты работы, целостность всех частей статьи и ее окончательный вариант.

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Проведение исследования — интерпретация анализ полученных данных.

Подготовка и редактирование текста — критический пересмотр черновика рукописи с внесением ценного интеллектуального содержания; участие в научном дизайне.

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