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CHARACTERISTICS OF CHONDROPLASTIC MATERIALS: ADVANTAGES AND DISADVANTAGES

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Abstract. ***Introduction.*** Articular cartilage, due to the peculiarities of its structure and the lack of active trophism, is not capable of independent regeneration. Existing clinical methods for cartilage tissue restoration have many limitations. The development of tissue-engineered structures remains an urgent task in the fields of medicine, biology, and materials science. ***Purpose of the study:*** to analyze existing materials for chondroplasty and identify their advantages and disadvantages. ***Materials and methods.*** The study design was a non-systematic literature review. The data search was carried out in the following databases: PubMed, ScienceDirect, eLibrary, Google Scholar. The search period was 15 years; most of the works included in the study were published in the last 5 years. Criteria for inclusion of works: availability of the full text of the articles, availability of histological studies, availability of statistical data analysis. The exclusion criteria for works were the absorbing nature of articles by one author (a more recent publication was included in the analysis). ***Results.*** During the work, it was found that both biological and synthetic polymers are used in the development of chondroplastic materials. Biological polymers have a high affinity for cell cultures but are not able to withstand significant mechanical loads. The solution of mechanical strength is the use of synthetic polymers. Chondrocytes are used as the main cell culture that influences the acceleration of defect restoration. Differentiation factors, especially factors from bone morphogenetic proteins group (BMPs), are also actively used. ***Conclusion.*** Biopolymers and synthetic polymers have both advantages and disadvantages, which leads to the need to use different types of polymers to ensure the mimicry properties of the structures being developed. The use of growth factors, differentiation factors, cell cultures and biologically active substances accelerate regeneration processes.

Key words: chondroplasty; tissue engineering; biological polymers; chondrocytes.

ХАРАКТЕРИСТИКА ХОНДРОПЛАСТИЧЕСКИХ МАТЕРИАЛОВ: ПРЕИМУЩЕСТВА И НЕДОСТАТКИ

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Резюме. ***Введение.*** Суставной хрящ, ввиду особенностей своего строения и отсутствия активной трофики, не способен к самостоятельной регенерации. Существующие клинические методы восстановления хрящевой ткани имеют множество ограничений, из-за чего разработка тканеинженерных конструкций остается актуальной задачей в области медицины, биологии и материаловедения. ***Цель исследования:*** провести анализ существующих материалов для хондропластики и выявить их преимущества и недостатки. ***Материалы и методы.*** Дизайн исследования представлен несистематическим обзором литературы. Поиск данных осуществляли в базах данных PubMed, ScienceDirect, eLibrary, Google Scholar. Глубина поиска составила 15 лет, большинство работ, включенных в исследование, опубликованы в последние 5 лет. Критерии включения работ: наличие полного текста рукописи, наличие гистологических исследований, статистического анализа данных. Критериями исключения работ считали: поглощающий характер статей одного автора (в анализ включали более позднюю публикацию). ***Результаты исследования.*** В ходе работы было установлено, что в разработке хондропластических материалов применяются как биологические, так и синтетические полимеры. Биологические полимеры обладают высоким сродством к культурам клеток, при этом не способны выдерживать значительные механические нагрузки. Решением проблемы механической прочности является применение синтетических полимеров. В качестве основной культуры клеток, которая влияет на ускорение восстановления дефекта, используются хондроциты. Активное применение находят также дифференцировочные факторы, в особенности факторы из числа костных морфогенетических белков (BMP). ***Заключение.*** И природные биополимеры, и синтетические полимеры имеют как преимущества, так и недостатки, что приводит к необходимости применения разных типов полимеров для обеспечения мимикрических свойств разрабатываемых конструкций. Применение факторов роста, факторов дифференцировки, клеточных культур и биологически активных веществ способствует ускорению процессов регенерации.

Ключевые слова: хондропластика; тканевая инженерия; биологические полимеры; хондроциты.

INTRODUCTION

The treatment of traumatic injuries and degenerative changes in articular cartilage represents one of the challenging tasks in the practice of orthopedic traumatologists. Articular cartilage (AC) is a unique connective tissue that plays a pivotal role in maintaining joint mobility by reducing mechanical friction at joint surfaces and absorbing shock during load transmission.

The absence of vascularization and innervation, the limited number of progenitor cells, and the restricted proliferative potrntial of mature chondrocytes contribute to the inability of cartilage tissue to repair itself. The currently employed methods of cartilage tissue transplantation, as well as subchondral bone transplantation, offer numerous clinical benefits but also possess drawbacks such as insufficient material availability, immunogenicity risks, and the complex preparation of implantable samples. Synthetic and natural biopolymers, which are devoid of these limitations, may be considered an alternative. Moreover, complex polymer compositions in conjunction with cells, growth factors, and differentiation factors can be used for cartilage tissue engineering. Biocompatibility, an extended resorption period, the enhancement of chondrogenesis, and the replication of the extracellular matrix structure of cartilage tissue are the main requirements for synthetic cartilage transplants.

Currently, there is no unified classification for articular cartilage damage across different localizations. The most widely used classifications in clinical practice are those proposed by Outerbridge [60] and by Bauer and Jackson [9]. The most comprehensive classification is that proposed by the International Cartilage Repair Society (ICRS) in 2000. Each of these classifications is based on the histomorphological changes in articular cartilage, characterized by the stage of progression or the severity of the damage. In describing the state of AC, the size of the defect as well as its anatomical and functional localization are also taken into account."

A great number of publications in the unit "Clinical Medicine are devoted to the epidemiologically most significant dis-

eases that lead to the development of degenerative-dystrophic changes in AC. Among the primary causes of osteoarthritis associated with autoimmune-driven pathogenesis are juvenile idiopathic arthritis and ankylosing spondylitis. Researchers also note that high doses of glucocorticosteroids used in the therapy of such conditions, as well as alterations in the composition and volume of synovial fluid, play a part. There have also been reports on osteochondritis dissection of the femoral condyle, or König's disease [15, 71]. Legg–Calvé–Perthes disease is recognized as the most frequent condition leading to hip osteoarthritis, attributed to the development of multiplanar deformities in the proximal femur and joint decentration. The ischemic component of this disease's pathogenesis may be associated with the subsequent degeneration of the femoral head's articular cartilage, with progression to deforming osteoarthritis consistently documented in multiple studies. [56, 62]. Limited research has focused on pediatric osteochondropathies, such as Osgood–Schlatter and Blount's disease, various forms of epiphyseal dysplasia, and congenital or acquired lower limb deformities. When these conditions persist with an aggressive course, they can lead to incongruence of the articular surfaces, resulting in uneven load distribution on the cartilage that, in turn, causes its thinning and degenerative changes [4].

The present work provides an analysis of the advantages and disadvantages of the materials most frequently used in cartilage tissue engineering. The article discusses methods to improve cell adhesion and proliferation, as well as the application of composite formulations designed to overcome the shortcomings of the scaffolds under review.

MATERIALS AND METHODS

The study design is presented as a non-systematic literature review. Data were searched in the following databases: PubMed, ScienceDirect, eLibrary, and Google Scholar. The search spanned a period of 15 years, with most of the works included in the study published within the last 5 years. The inclusion criteria were as follows: availability of the full text of the manuscript, the presence of histological studies, and the inclusion of statistical data analysis. Studies were excluded if they represented repetitive work by the same author (only the most recent publication was included in the analysis).

RESULTS AND DISCUSSION

Cartilage tissue — a special type of connective tissue distinguished by its dense and elastic extracellular matrix. Three types of cartilage are recognized:

- Hyaline cartilage — a translucent cartilage tissue with a high content of collagen fibers; it forms the articular surfaces of long bones as well as the edges of the ribs.
- Elastic cartilage — yellowish in appearance due to the presence of elastic fibers; it forms the auricle and the laryngeal cartilages.
- Fibrocartilage — a variant of hyaline cartilage that contains numerous bundles of collagen fibers; fibrocartilage forms intervertebral discs and serves as the attachment sites for tendon–muscle fibers to bones.

Articular cartilage is a type of hyaline cartilage that covers the epiphyses of bones and serves as an interlayer between them. AC is composed of collagen fibers and chondrocytes, which are spherical cells with an average diameter of 13 μm [44]. Chondrocytes constitute 5–10% of the cartilage volume, and their primary role is the formation of the extracellular matrix (ECM), which consists of collagen and proteoglycans. The matrix also contains a large amount of water with dissolved sodium, chloride, and potassium ions. In addition to its joint function, the ECM serves as a barrier protecting the chondrocytes from damage [34].

Articular cartilage is entirely devoid of nerve endings and vascular structures. Chondrocytes are nourished by diffusion from the synovial fluid. The lack of direct nourishment and innervation does not allow cartilage tissue to recover independently, which is why the development of highly effective materials for the repair of articular surfaces remains a critical challenge in medicine [50].

In addition to its protective function for the bone epiphyses, articular cartilage also performs an amortizing role; the presence of synovial fluid and its smooth surface reduce friction in the joints during movement, thereby ensuring the congruence of the articular surfaces. Despite these adaptive features, AC remains vulnerable to degeneration under various stressors.

MATERIALS FOR CARTILAGE REPAIR

The aforementioned histological and morphological features of hyaline cartilage, along with the multitude of pathologies that lead to its damage, underscore the need to develop materials that can restore and replace the lost cartilage volume.

Materials for chondroplasty — whether for complete or partial restoration of articular cartilage in surgery — can be classified into the following groups: biological materials (including autografts and allografts, xenografts, and biologically active molecules of both protein and non-protein nature), synthetic materials (for example, polyethylene glycol and polylactide), which are obtained by chemical synthesis, composite materials which combine several biological and/or synthetic materials.

TRANSPLANTS

When discussing cartilage transplants, it is essential first to classify them into three categories: autologous transplants (the donor is the same as the recipient), allogeneic transplants (the donor and recipient belong to the same species), and xenotransplants (the donor and recipient belong to different species).

Autotransplantation. Autologous repair is considered the "gold standard" in regenerative medicine. Since the graft is harvested directly from the recipient's own donor site, many immunological issues associated with defect repair are eliminated. In practice, small fragments of cartilage tissue or pieces of bone tissue with overlying cartilage are often used as grafts [2].

The primary drawback of this approach is the extremely limited volume of tissue that can be harvested. Apart from that, extra surgical interventions are required for the autopsy of the graft, which may cause pain at the donor site [24]. Nevertheless, according to I.M. Zazirny and R.Ya. Shmigelski (2015), more than 70% of the interventions resulted in improved outcomes [3]. In cases of massive cartilage surface defects, the insufficiency of donor tissue and the limited available harvest sites become a significant problem. To overcome this issue, some groups of clinicians have adopted a combined repair approach that uses autotransplantation supplemented by various materials (including collagen sponges) to compensate for the lost volume of articular cartilage [5].

Allotransplantation. Another approach to address the challenges associated with autotransplantation is the use of allogeneic transplants. Cartilage allografts were actively used until around 2010, after which the number of publications on the subject began to decline. Nevertheless, this method has been studied extensively. Typically, the grafts consist of fragments of bone tissue with an adjacent layer of cartilage [51], which is due to the fact that cartilage receives nourishment not only from the synovial fluid but also via diffusion from the subchondral bone [49].

Since 1981, allotransplantation has been introduced into pediatric orthopedic practice by Professor V.L. Andrianov, who proposed to use a demineralized bone-cartilage allograft (DBCA) of cadaveric origin for treating the consequences of acute hematogenous osteomyelitis of the proximal femur, which was accompanied by destructive hip dislocation. Later, in 1992, S.V. Filatov proposed the use of perforated DBCA, and the technique was validated by satisfactory functional outcomes in the postoperative period. The surgical technique involves reshaping the femoral head into a spherical form in cases of pronounced deformity and fixing the graft with its cancellous surface facing the acetabulum, followed by joint decompression.

The cadaveric origin of the graft can significantly increase the available donor material compared to autografts. It is worth mentioning that cadaveric grafts have been widely used in the production of composite materials [14].

Allogeneic grafts require specific preparation and preservation methods for transportation. Currently, there is no consensus on which preservation method for cartilage tissue is preferable for future transplantation into the defect area. The main approaches which minimally affect the structure of cartilage tissue are divided into two types: the use of native chondral structures and the application of cryogenic technologies to preserve the cartilage for later implantation [10].

Xenotransplants. In many countries, ethical and legal challenges complicate the preparation of allografts. At the same time, the availability of animal tissues makes xenotransplants an attractive alternative to allo- and autotransplantation.

Xenogeneic transplants are tissues obtained from various animals, particularly pigs and cattle. In many cases, it is not the tissue fragments themselves that are used, but rather cells harvested from the animal donor [6].

The primary challenge associated with xenotransplants is their immunogenicity. Various approaches have been employed to reduce it, including lyophilization, freezing, chemical treatment, and gamma irradiation. However, due to the unique composition of cartilage tissue, these methods can lead to a reduction in its chondrogenic potential. Another significant concern is the potential transmission of infections [1].

Despite these challenges, the literature reports both positive and negative outcomes in experimental studies [63]. In a study [80], it was suggested that the observed results might be related to the duration of the studies. In short-term experiments, the outcomes were better than in long-term ones. Moreover, the choice of the experimental model and the corresponding type of recipient plays a crucial role: studies conducted in small rodents have obtained better results than those in other species.

BIOLOGICAL POLYMERS

Natural polymers such as collagen, chitosan, alginate, gelatin, and many others are actively employed in cartilage tissue engineering. Many of these natural polymers exhibit high cell affinity, are easily modified, resorbed, and effectively mimic the extracellular matrix (ECM) of cartilage tissue. However, their autonomous use is limited by low mechanical properties and, in many cases, a high resorption rate, which does not allow the effective restoration of cartilage function.

Collagen. Collagens are a family of proteins that are among the most widely represented in the human body.

They constitute the most important component of the ECM and, in their native state, offer excellent biocompatibility, low immunogenicity, and bioresorbability. Collagens are composed of polypeptide chains that contain tripeptide sequences of glycine, proline, and hydroxyproline. These tripeptide sequences form a structure that ensures the stability and mechanical properties of collagen matrices [76].

Collagens serve as an excellent matrix for cultivating various cell lines and actively interact with growth and differentiation factors, thereby enhancing the proliferation and adhesion of cell cultures [74]. Collagen matrices can be produced from collagen obtained from fish [79], cattle [86], or recombinant human collagen [88]. Despite their outstanding biological characteristics, collagens exhibit low mechanical strength [35] and a high rate of biological resorption [31], which considerably limits their application — especially for articular cartilage replacement.

A primary strategy to overcome the limitations of collagen is to employ composite materials. For example, in study [29], polylactide and chitosan were used to improve the mechanical properties of collagen matrices. Other studies have modified mechanical characteristics by incorporating elastin, polyglycolic acid (PGA), or polyethylene glycol (PEG) [61].

While collagen itself is an excellent biological polymer for cell cultivation and implantation into defect areas (as demonstrated in [19]), the addition of various biologically active molecules can further enhance tissue repair processes or influence cell proliferation on collagen matrices [68]. Since chondrogenesis is closely linked with osteogenesis, bone morphogenetic proteins (BMPs) are often used [69] — under certain conditions, they can direct the differentiation of mesenchymal stem cells (MSCs) toward a chondrocytic way and affect the rate of ECM formation during long-term *in vitro* cultivation on collagen substrates [46].

Chitosan. Chitosan is a natural, hydrophilic, polycationic biopolymer obtained from chitin. Structurally, it resembles cartilage and bone tissue, which makes it a good candidate for mimicking the ECM [78].

Chitosan is a deacetylated product of chitin and is composed of β-(1→4)-2-acetamido-D-glucose and β-(1→4)-2-amino-D-glucose units [18]. Due to the presence of amino and hydroxyl groups, the polymer forms both intermolecular and intramolecular hydrogen bonds. The abundance of multifunctional surface chemical groups enables modification of its surface with growth factors and cell differentiation factors [8]. Chitosan exhibits excellent biological and cytological compatibility and bioresorbability; its surface easily facilitates the formation of a protein coating, creating a native-like environment for cells [23].

The disadvantages of chitosan include low mechanical strength and poor thermal stability. These issues are typically handled by applying composite materials; for example, a study [41] utilized polylactide. PEG has also been applied to improve its mechanical properties [89].

Alginate. Alginate is a polysaccharide obtained from brown algae. It is widely used in medicine due to its biocompatibility and non-immunogenicity. Due to its gel-like structure, alginate serves as an excellent substrate for cell growth [21].

Alginate is composed of two types of blocks: D-mannuronic acid (M-block) and L-guluronic acid (G-block). Variations in the ratio and chain lengths of these blocks lead to changes in the mechanical characteristics of alginate scaffolds [12].

Alginate is degraded by enzymes of the alginate lyase class which are not typically found in mammals rendering this material essentially non-resorbable when implanted *in vivo*. Nonetheless, it exhibits a high capacity for chondrogenesis and osteogenesis, permitting its use in both *in vitro* and *in vivo* studies [48]. Another limitation of alginate is its gelation, which prevents the formation of complex porous structures.

To handle these issues, various composite formulations have been developed, they combine alginate with chitosan [67], collagen [32], or numerous synthetic polymers [75] to impart additional mechanical and biological properties. Like many other biological polymers, alginate is frequently used in conjunction with growth and differentiation factors [25]. Moreover, numerous studies have demonstrated the positive effect of incorporating hydroxyapatite particles into alginate matrices [92].

Silk fibroin. Silk fibroin is one of the oldest biomedical polymers. It consists of thin fibroin fibers coated with a globular protein known as sericin. The presence of this foreign protein often triggers an immune response; as a consequence, several simple and accessible methods — physical, enzymatic, and chemical — have been developed to remove sericin from fibroin fibers [47]. Silk fibroin is taken from various organisms and is subsequently purified to remove sericin. Depending on the source and processing methods, the mechanical properties of fibroin fibers can vary [64].

Due to their fibrous structure, materials derived from fibroin can tolerate prolonged cyclic loading — an important feature for implantation as a replacement for defective cartilage tissue [37]. Besides that, fibroin-based constructs exhibit a long *in vivo* resorption time, allowing for the gradual replacement of cartilage tissue [38].

The primary disadvantage of silk fibroin is its immunogenicity; despite high-quality purification processes, there

is considerable evidence of delayed immune responses to both silk fibers and the implanted constructs [26].

Hyaluronic Acid. Hyaluronic acid is a disaccharide composed of N-acetylglucosamine and glucuronic acid. It is favored because it is one of the main components of synovial fluid, naturally supports chondrocyte proliferation, and enhances cartilage tissue repair. Its molecular structure promotes easy cell adhesion to its surface [52].

Hyaluronic acid is a resorbable, biocompatible, and non-toxic material. Depending on its molecular weight, it exhibits varying mechanical properties and lubricating characteristics — both essential for cartilage tissue function [96]. According to [36], at certain shear rates, hyaluronic acid behaves similarly to water, which limits its use as a friction-reducing material on joint surfaces.

With advances in bioprinting using hydrogels, hyaluronic acid is now used either as a base material or as a coating for various printed constructs [84]. In addition, hyaluronic acid is used in composite formulations with alginate [11], collagen, and gelatin [58] as bio-inks for 3D bioprinting. Its widespread use as a component in intra-articular injections for gonarthrosis of varying severity has long been established as an effective and minimally invasive method [95].

Gelatin. Gelatin is a fibrous protein obtained from partially hydrolyzed collagen. It exhibits high biocompatibility and is bioresorbable, which makes it suitable for various medical applications. Due to its functionalization, gelatin is widely used for drug delivery and in tissue engineering. Its polyionic nature allows for the easy conjugation of polysaccharides, growth and differentiation factors, proteins, nucleotides, and other therapeutic molecules [59].

In recent years, gelatin has become important in the development of materials for cartilage tissue engineering due to the ease with which printed samples can be stabilized post-3D printing. In particular, methacryloyl gelatin (GelMA) has attracted considerable attention. Hydrogels based on GelMA possess an ECM-like structure, enabling the creation of scaffolds that closely mimic native tissue [91]. GelMA can be synthesized by various methods, which allows for the modulation of the mechanical and chemical characteristics of the resulting matrices [43]. However, according to a study [85], methacryloyl gelatin may have negative effects on cell cultures, which is attributed to the need for photoinitiators during the crosslinking process following printing.

Bacterial cellulose. Among naturally occurring polymers, cellulose is one of the most common. It forms the cell walls of plants and is also secreted by many bacteria [7]. Bacterial cellulose (BC) is preferred because it has a more branched nanofiber structure, providing a greater surface area at the same volume. According to [70], cellulose fibers are easily modified, which allows one to modify the structure and properties of matrices based on BC.

The mechanical strength, crystallinity, and moisture-retention characteristics of bacterial cellulose depend not only on the type of bacteria used to produce the material but also on the composition of the culture medium, the addition of various substances, and the cultivation conditions. Despite these advantages, BC exhibits a very long resorption period, and cells do not show a high degree of adhesion to its surface [66]. The main method of dealing with cell compatibility issues is the addition of collagen [94] or alginate [65].

Synthetic polymers

Synthetic polymers have a longer resorption period compared to natural polymers, and controlling the degree of polymerization makes it possible to influence mechanical characteristics, matrix structure, and degradation.

Synthetic polymers are generally preferred because of their superior mechanical properties compared to natural polymers. Nevertheless, purely synthetic polymers are currently almost never used independently for cartilage tissue repair due to low cell compatibility and the absence of therapeutic features. In most cases, synthetic polymers — such as polyglycolic acid, polylactic acid, polyethylene glycol, and polycaprolactone — serve as scaffolds in combination with natural polymers, cells, and agents that enhance proliferation and influence cell differentiation.

PGA. Polyglycolic acid (PGA) is a linear crystalline hydrophilic polyester. This polymer demonstrates good adhesive properties, it is non-toxic and bioresorbable, and has high hygroscopicity, which allows it to be used as a cell carrier in cartilage tissue repair [13].

Due to the specifics of cartilage tissue regeneration, polyglycolic scaffolds are often used together with cell cultures [93]. Various substances that influence tissue differentiation at the implantation site are also widely applied [30].

Like other polyesters, PGA is responsive to extrusion, injection molding, and compression molding [73]. Some studies [27, 33] have shown that PGA can serve as an independent material for 3D printing. In addition, many research workers employ the copolymerization of PGA with polylactide (PLA) to obtain the copolymer PLGA [20], which makes it possible to control printing quality as well as the hydrophilic properties of the material. It should also be noted that PGA degradation leads to the release of acidic products, which reduces the material's biocompatibility and can cause inflammatory reactions at the implantation site. A partial solution to this issue is the use of compositions with polylactide [40].

PLA. Polylactide is a linear polyester with lower crystallinity than PGA. Its key advantages include thermal stability, biocompatibility, and the non-toxicity of both the material itself and its resorption products. Polylactide has high viscosity and thermoplasticity; therefore, it is primarily used for 3D printing and for manufacturing scaffolds for tissue repair [22].

According to [54, 87], polylactide matrices can be used as autonomous cell carriers; however, the addition of biological polymers improves their *in vitro* compatibility by enhancing cell adhesion and proliferation [45]. Growth factors are also employed for the same purposes, as in the case of PGA [90].

PEG. Polyethylene is a water-soluble polymer that is not recognized by the immune system [17]. Two main markings are used for polyethylene: polyethylene glycol (PEG) with a molecular weight below 20,000 Da, and polyethylene oxide (PEO) with a higher molecular weight.

Due to its solubility, interest in polyethylene has grown in recent years. Polyethylene is increasingly used in 3D printing as a carrier gel [42]. Nonetheless, its native mechanical characteristics are inadequate for it to serve as an autonomous material in tissue engineering. For that reason, numerous composite materials with various synthetic polymers have been proposed [28].

The primary advantage of this polymer is its rapid and almost unhindered elimination from the body. By binding to other substances, including resorption products, polyethylene can also intensify their excretion [16]. Thanks to this property, polyethylene glycol is frequently employed as a carrier for drug delivery [53], including the delivery of growth factors to the implantation site [82].

PCL. Polycaprolactone is a synthetic semicrystalline polyester characterized by high mechanical strength, elasticity, and biocompatibility, and it is also bioresorbable [77]. Like PEG, its degradation products are easily excreted from the body [55]. Polycaprolactone is widely used in cartilage surgery due to its biomechanical properties, which closely resemble those of native tissue [81].

However, polycaprolactone is hydrophobic, which is its main disadvantage since cells cannot easily spread on its surface, leading to poor adhesion and, consequently, low viability of cell cultures [83]. For this reason, this polymer is primarily combined with other substances (for example, polylactide) to improve its mechanical properties [72]. Another approach to enhancing cell adhesion is to add natural polymers, to which cells actually adhere, while the polycaprolactone serves as a supporting scaffold [39]. Numerous studies use various agents to improve cell adhesion, particularly hydroxyapatite particles, which coat the surface and enable cells to attach more effectively [57].

CONCLUSION

Effective restoration of cartilage tissue damage remains a challenging, yet highly significant task. As demonstrated in this article, the most frequently used approaches and materials have numerous disadvantages. The independent use of natural biological polymers enables to create constructs exhibiting biocompatibility and affinity for cell cultures; however, these materials possess very low mechanical properties. This issue can be handled by employing synthetic polymers, which, in turn, have a longer resorption period, can tolerate prolonged static and dynamic mechanical loads, and may be used for cartilage tissue repair. At the same time, the autonomous use of synthetic polymers is limited by poor adhesion of cell cultures to their surfaces.

As indicated by multiple sources, the integration, proliferation, and regeneration of cartilage tissue at the implantation site can be accelerated by using various additional agents, especially growth and differentiation factors. Composite constructs pre-loaded with cell cultures and various factors on their surfaces demonstrate better outcomes compared to implantation of composite or single materials.

The development of constructs for bone tissue engineering requires the use of various synthetic and natural polymers to ensure that the designed constructs mimic the biological and mechanical characteristics of native cartilage tissue. It is also necessary to apply multiple biologically active molecules and cell cultures, thereby allowing the construct to approximate native tissue as closely as possible and speeding recovery in the postoperative period.

ADDITIONAL INFORMATION

Author contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

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