https://doi.org/10.52889/1684-9280-2025-2-76-12-19

Review article

The use of bone grafts in combination with additive technologies in orthopedic practices

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Abstract

The issue of selecting a material for bone reconstruction in orthopaedic surgery remains relevant and continues to evolve in tandem with technological advancements.

This review aims to analyze one relatively novel aspect of orthopedics, namely, the combined use of bone grafts with 3D technology.

A literature search was conducted using modern actual European and American medical data bases. All search results were filtered by language and period of 2014-2024. There were more then 10000 articles by keywords and after exclusion remained 10 articles. For analyzing cohort studies we used Coleman Methodology scale and table viewing for each of study for analyzing demographic data, clinical and radiological outcomes. There were a different types of researches, including clinical case study, retrospective cohort study, and prospective cohort study. All the articles reviewed provide radiological findings and four present clinical outcomes after treatment.

The findings from the research have demonstrated the potential of the chosen approach. However, at present, there has been a relatively small number of published works on the relevant topic, even including descriptions of clinical cases. It is certainly true that the integration of additive technologies with bone allotransplantation has great potential for complex orthopedic cases and can be recommended for widespread adoption in global practice.

Keywords: bone cyst, 3D printing, bone defect, bone allograft, allograft, additive technology.

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J Trauma Ortho Kaz 76 (2) 2025: 12-19
Recieved: 22-01-2025
Accepted: 11-02-2025

Introduction

Currently, osteosynthetic material should be readily available in sufficient quantities to fill major defects in cancerous lesions and be sufficiently flexible to restore physiological levels of joint surfaces during surgeries on periarticular areas. In addition to meeting the basic requirements for biological compatibility, implantable bone matrices must also possess satisfactory osteoconductive abilities [1]. The "gold standard" for selecting such a material remains autologous bone, but the process of obtaining bone samples is a further source of trauma for patients, which carries certain infectious and surgical risks. Additionally, the amount of autologous bone that can be collected at one time is limited, and it cannot be used to replace large amounts of bone tissue [2]. Therefore, orthopedic surgeons are increasingly challenged by the question of selecting an osteosynthetic material that is either synthetic or allogeneic. In the search for a suitable transplant, both new synthetic materials and innovative methods for harvesting donor bone grafts have been investigated and employed.

The synthetic materials used in bone tissue engineering are more pliable and financially affordable, giving greater freedom to replace the bone cavity and fill the defect completely. Fast production methods such as powder-based 3D printing, laser melting, and inkjet printing make it possible to create customized models serving as an adequate replacement for defects, and their porosity helps with rapid and acceptable vascularization and further remodeling. However, plastic fabrication requires high temperatures, eliminating the possibility of adding bioactive materials and limiting mechanical strength, preventing early loading and improving the development of damaged limbs [3]. As a result, this leads to a longer recovery period and increased risks of early breakage and repeated fracture at the surgical site. Some success has been found with bone cement based on calcium phosphate, which allows the modeling of the necessary defect directly in the operating room through extrusion at room temperature. However, its osteoconductive characteristics are only close to those of real bone tissue. The high cost does not permit adequate filling of large bone defects, but it is a promising option for certain applications [4].

In parallel, many variants of bone allograft harvesting techniques are being developed, which makes the possibility of creating a local bone bank affordable and technically simple. According to the results of a retrospective cohort study, it was found that an allograft is an acceptable, safe, and effective material for the restoration of large bone defects [5]. Additionally, during a retrospective analysis of 164 histories, it was concluded that it is advisable to use bone allografts in the treatment of benign bone formations with a low complication rate [6]. All available allograft harvesting approaches aim to achieve absolute biological safety of the donor's bone while fully preserving its tissue structure and osteoconductive properties. To do this, various combinations of physical and chemical methods are used, such as the rapid freezing of spongy bone tissue, chemical treatment with reagents at high concentrations, treatment of bone tissue at feverish temperature, or ultrasound. The techniques proposed by many institutes have been assessed and used for many years in different countries of the world, depending on the adaptability of the local infrastructure to a particular method.

Thus, the youngest technique is a combination of the two previously mentioned methods, namely, the production of bone allografts not according to the standard procedure but individually, using additive manufacturing technologies. The constructive interaction of these two methods is even more intriguing, as when they are used together, the process of filling bone defects is technically straightforward and available in most developed and emerging countries. This is thanks to both the rapid development and widespread adoption of 3D printing and the prevalence of accredited allograft harvesting methods.

According to our data, there has been no systematic review of the use of allografts in the surgical treatment of bone cavity defects using additive technologies. Therefore, considering the novelty of this area and the high potential of the combination of two modern technologies for filling bone defects, this review aims to study this issue and explore the existing relevant work carried out in this area.

The research question is: What techniques and results are currently available for using bone allografts with additive technologies in the treatment of bone cysts?

The purpose is to study the feasibility of using bone allografts in combination with 3D printing.

Materials and methods

Database and selection

A literature search was conducted using PubMed, Wiley Online Library, Web of Science Core Collection, Europe PubMed Central (PMC), Springer Link, and the Cochrane Library. The search was performed on 8 April 2024. The following key search terms were used: "bone cyst", "3D printing", "bone defect", "bone allograft", "allograft", and "additive technology". The results of the search were carefully analyzed using search filters to select articles published in English no later than 2014 and related to the field of orthopedic surgery. From the resulting articles, only those that studied the combination of allografts with 3D printing for the surgical treatment of bone defects were selected.

The exclusion criteria for this study were as follows:

1. Literature not in English language.

2. Abstracts, editorials, and review articles.

3. Experimental work on laboratory animals and articles on tissue engineering.

4. Articles that did not discuss the use of allogeneic tissue.

5. Articles that did not consider the use of three-dimensional (3D) printing.

6. Articles that did not cover clinical or radiological findings.

7. Articles published before 2014.

8. Research in bone tissue engineering area

Two reviewers independently conducted the literature search process to ensure accuracy. Next, a third author reviewed and excluded any duplicate articles. Articles were also screened, and those whose content, after careful consideration, did not completely align with the subject matter of the study were eliminated. These included articles that focused on laboratory studies of allografts under laboratory conditions using tissue engineering or on the use of three-dimensional (3D) modeling in the preoperative preparation phase and not during surgery. This systematic review was conducted according to the guidelines established by PRISMA (2020) [7]. The technical process for searching is illustrated in Figure 1.

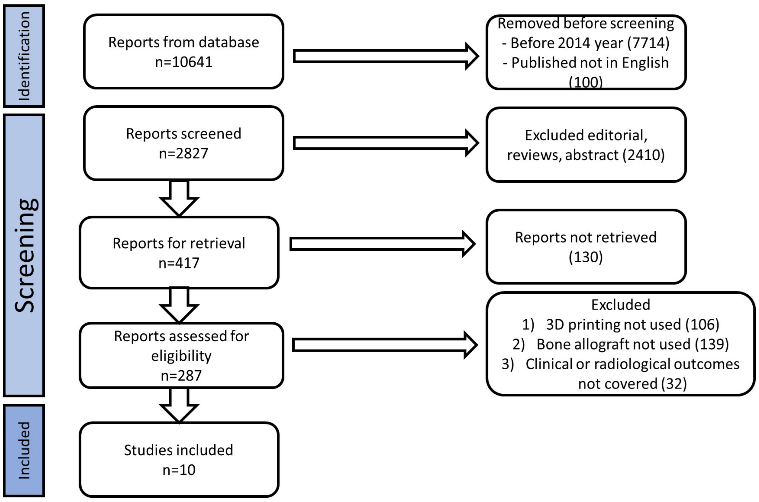

Figure 1 - Literature Search Strategy

Given the novel nature of the research field, the resulting number of articles is believed to be sufficient for research. Additionally, the authors of this paper had to accommodate for the variation in design among the publications analyzed. Therefore, of the 10 selected papers, five were case reports and five were cohort studies. These letters were further evaluated by an external reviewer using the Coleman Methodology Scale [8], which is widely employed in orthopedic research. This scoring system consists of two parts: part A encompasses the scope of the study, average follow-up duration, number of surgical interventions, type of study, diagnostic information, description of surgical techniques, and postoperative rehabilitation. Part B covers the assessment of results and the selection process. The overall score ranges between 0 and 100, with a higher number indicating a lower influence from randomness, bias, and associated factors. Two reviewers independently read the full texts of each study and assigned marks. The average of the two reviewers' marks was then used as a proxy for the study's quality.

Data Collection. We collected the following information from each of the included publications: author, year of publication, type of study design, number of cases reported in cohort studies, age of the patients at the time the study was conducted, duration of follow-up, scales used to measure clinical outcomes, conclusions regarding clinical outcomes, methods used for instrumental evaluation of outcomes, and conclusions regarding instrumental outcomes.

Results

Ten articles published from 2015 to 2022 have been analyzed. Of those, five analyzed articles described a clinical case study of the use of additive technology in combination with an allograft, four articles described a series of cases within the scope of a retrospective cohort study, and one article presented a prospective cohort study. In two articles, the use of an allograft was performed during surgery on the femoral condyles. Four articles described the use of original surgical techniques to correct the tibia, and two articles described the use of a combination of additive technologies and an allograft on the proximal humerus.

Additionally, in the article by Zhigang Wu et al., a series of cases are described within the framework of a developed bone banking system that uses a virtual 3D archive for the treatment of bone cancer at various locations [9].

Chao Dong and colleagues describe a series of cases from a retrospective study in which 17 patients with bone tumors underwent surgery using personalized guides that were printed on a 3D printer. During treatment, 12 of these patients received grafts, 7 received a combination of allogeneic and autologous grafts, 3 received only allogeneic grafts, and 2 received only autologous grafts [10].

Clinical case descriptions: The patient population examined in this study ranged in age from 7 to 40 years. The demographic data, as well as information on the surgical procedures, are presented in Table 1.

Table 1 - Demographic data for clinical case studies

Author	Year	Age of patient	Observation period	Operation area
Di Felice Ardente, P.	2020	40	1,3,12	Proximal humerus after a stale (1 month) Hill-Sachs fracture
Okoroha, K. R.	2018	26	1,4,12,18	The medial condyle of the left femur following the destruction of a previously placed autograph
Eero Huotilainen, Mika Salmi, Jan Lindahl	2019	22	3,4,12	The lateral condyle of the femoral bone, following an unsuccessful surgery for dissecting osteochondritis, using an autograft
Alessandri, Giulia	2022	7	0	Proximal tibia in varus deformity of both lower extremities
Yang, Hongsheng	2022	32	44	Distal Tibia: Condition after Tumor Resection (2012) and Osteosynthesis of Allograft Fracture (2014) In 2015, the patient underwent the removal of the metal fixers following their tibia condition after tumor resection in 2012 and osteosynthesis for an allograft fracture in 2014

All the articles reviewed provide radiological findings and four present clinical outcomes after treatment. The mean age of the patients was 25.4 years, and the mean follow-up period was 17.2 months.

Cohort Studies. The remaining four articles presented the results of using a specific technique without comparing to a control group. All four articles presented clinical outcomes, and four articles presented radiological findings.

Two articles described cases of tibia intervention, and one article described the use of an operative technique for the proximal humerus. Two articles provided data on the various surgical locations. The demographic data for this type of article are presented in Table 2.

Table 2 - Demographic data for cohort studies

Author	Year of publication	Type of Study	Number of patients	Age of patients	Observation period	Coleman's scale ball
Russo et al	2021	Retrospective study	4	60,5	37,3	87
Steele J. R. et al	2020	Retrospective cohort study	15	54	26,5	33
Wu, Z. G. et al	2015	Retrospective cohort study	14	21,7	27,5	60
Dong, Chao et al	2022	Retrospective cohort study	17	25+-19	26,5	75
W.V. Genechten et al	2022	Prospective cohort study	30	48+-13	12	106

The average number of patients was 16, the average age of the patients was 52.3 years, and the average follow–up period was 25.9 months. Coleman Methodologe Scale average score is 72.2.

Outcomes. In two studies, researchers Yang, Hongsheng, and others, as well as researchers Dong, Chao, and others, used the MSTS scale to evaluate clinical outcomes [10, 11]. Authors Van Genechten, Wouter, and colleagues evaluated clinical outcomes using several scales, including the KOOS10 [12] The same scale was also used by Eero Huotilainen, Mika Salmi, and Jan Lindahl, [13] and other researchers used different criteria to evaluate clinical outcomes, which we believe to differences in the geographical location of the studies and the usual structure of the research methodologies within their own academic schools. Additionally, it was also important when choosing a scale for clinical assessment within cohort studies that some articles reported cases of surgical treatment for pathologies in both the upper and lower limbs, which prevented the use of standardized scales such as the KOOS.

Almost all the authors in their articles used X-rays for instrumental assessment of allograft survival. Also in separate articles, namely, Alessandri, Julia, and others, the measurement of instrumental indicators in the form of angles of mind, aTFA, and FC-TC was used as part of the assessment of the results of treatment of orthopedic pathology [14]. Most of the authors while working on oncological diseases of bones, assessed the restoration of bone tissue within the operated limb and the presence of generalized metastases. We do not consider CT and/or MRI scans of the chest and abdominal cavity used for this diagnosis when considering the assessment of treatment outcomes due to the lack of informative data within the scope of the area we studied. The assessment of the location of the allograft and bone resorption in the operated area using CT studies was carried out in four out of 10 articles.

Discussion

Based on the previous articles and numerous other studies, bone allografts can be considered suitable and universal materials for repairing defects in tubular bone. According to Chen CJ and Brien EW [15], bone allografts have fewer complications than other bone substitute materials when used to fill large bone defects in orthopedic oncology, including autotransplants. Furthermore, in experimental studies, histological analyses have demonstrated that bone allografts result in significantly faster bone healing than hydroxyapatite grafts [16].

The use of allografts allows the preservation of bone structure, promoting faster and more complete repair of bone defects, making allografts suitable for use in adult cyst treatment and pediatric orthopedic applications [17].

Thus, the clinical case of a 7-year-old girl suffering from spondyloepiphyseal dysplasia with a complication due to pronounced varus deformity of both lower extremities described in the article by Giulia Alessandro, Leonardo Frizziero, and others is a good example. The primary method of surgical treatment, namely, tibial hemiepiphysiodesis with tension band plates (TBPs), showed its ineffectiveness was ineffective after two years of follow-up. The authors performed an osteotomy of the tibia with a customized allograph and individual instruments printed on a 3D printer. X-ray results after surgery showed significant but incomplete correction of the deformity. Another disadvantage of this article is the lack of dynamic data on the patients during further follow-up in dynamics. Given the history of previously unsuccessful surgery, it is difficult to ensure a positive outcome of the chosen treatment [14].

Also noteworthy is the description of the case by the authors Pierluigi Di Felice Ardente, MD, Fernando Menor Fusaro, MD, etc. Unlike the rest of the articles presented, it describes the restoration of bone integrity after injury and not after orthopedic or oncological disease. Thus, a Hill-Sachs fracture in a 40-year-old patient was diagnosed 2 months after the injury using CT. To eliminate defects in the articular surface of the humeral head, alloplastic tactics using personal 3D-printed blade guides for both the injured area of the recipient and the donor allograft were chosen. The results of control observations after 1, 3, and 12 months showed excellent fusion of allograft and bone, as well as the full range of movements of the shoulder joint as a good clinical result. However, as the authors themselves noted, this method has a limitation in the form of the need for CT, which cannot be used in routine studies of emergency traumatology. It also takes several days to prepare, which predictably leads to worse results than early surgical treatment [18].

In an article by John R. Steele, MD, Rishin J. Kadakia, MD, et al., a comparison was made between the use of allograft and a 3D-printed titanium sphere as a blocking component in arthrodesis of the talus-tibial joint with retrograde BIOS nail [19].

Special attention should be given to the description of a virtual bank of three-dimensional (3D) models of existing allografts created based on the orthopedics department of the Lanzhou General Hospital, Lanzhou Military Region. Over the past four years, high-technology operations using preselected virtual allografts based on their volume, size, and structural features have helped to save staff time and effort during preoperative planning and reduce surgery time and intraoperative blood loss. The authors describe these successes as necessary for a more comprehensive examination in a multicenter study.

A pronounced limitation in the number of patients is noted in the authors Russo. R, etc. The description of 4 cases, of which one patient had allograft rejection, cannot be called indicative and sufficient for recommendation [20].

During our literature review revealed that the included articles reported satisfactory graft survival rates with a low incidence of postoperative complications.

Table 3 - Clinical and instrumental outcomes

Authors	Year of publication	Clinical outcomes scale	Clinical outcomes	Instrumental methods	Instrumental outcomes
Di Felice Ardente, P. et al	2020	Disabilities of the Arm, Shoulder, and Hand scale,		X-ray, CT	Good final positioning of the allograft and its fixation with screws 1 year after surgery
Okoroha, K. R. et al	2018	Knee ROM	At 4 weeks postoperatively, she had a ROM of 0°–125°, with mild pain over the medial joint line. At 4 months, she progressed to nonimpact, aerobic exercises and then to low-impact aerobic exercises at 6 months. Full ROM after 12 months	X-ray	One-year postoperative radiograph demonstrating excellent incorporation of the allograft into the medial femoral condyle
E. Huotilainen et al	2019	KOOS	Significant reduction of pain syndrome 6 months after surgery	X-ray, MRT	Three months after surgery on the X-ray, satisfactory standing of the graft structure and the engraftment process of the allograft were noted. Four months after surgery, MRI scans revealed a lack of strong vascularization of the allograft
Alessandri, Giulia	2022	-	-	X-ray (MAD: mechanical axis distance; aTFA: anatomical tibiofemoral angle; FC-TS angle: femoral condyle-tibial shaft angle)	There is a good correction (MAD from 100 to 39; a TFA from 45 to 3; FC-TS from 49 to 86) in the right tibia and less in the left (MAD from 100 to 51; aTFA from 44 to 15; FC-TS from 55 to 72)
Y. Hongsheng et al	2022	Musculoskeletal Tumor Society score	44 months after the last operation found the patient to be independent in all activities of daily living, with normal weight-bearing and mobility. However, he did have limited movement of the ankle joint and had difficulty with squatting MTS score of 24.	X-ray, CT	X-ray showed a small amount of callus formation at the fracture end of the allograft bone and fibula. While the fracture did not heal completely, the intramedullary nail had closely adhered to the surrounding bone. A CT scan showed that the intramedullary nail system matched well with the tibial bone marrow cavity, and the biomaterials on the surface of the intramedullary nail were well integrated with the host bone
R. Russo et al	2021	MEPS, DASH and VAS	MEPS, DASH, and VAS were 90 (80-100), 11.8 (0-25), and 1 (0-3) points, respectively	X-Ray, CT	X-rays at a 1-year follow-up didn't show any resorption signs. X-rays and CT scan at 2-year follow-up showed partial peripheric allograft resorption in all cases, without screw prominence
Steele, J. R. et al	2020	-	The rate of total fused articulations was significantly higher in the 3D sphere group (92%) than in the femoral head allograft group (62%; p = .018). The number of patients achieving successful fusion of all 3 articulations was higher in the 3D sphere group (75%) than in the femoral head allograft group (42.9%, p = .22).	X-ray, CT	The rate of graft resorption was significantly higher in the femoral head allograft group (57.1%) than in the 3D sphere g
Wu, Z. G.	2015	Functional score	They had an average functional score of 25.7±1.1 points.	X-ray	X-ray film on follow-up showed good bone healing. There was no joint narrowing, subchondral bone collapse, limb-length discrepancy, or screw loosening in any of the patients
D. Chao et al	2022	MSTS	MSTS Score was 24 (range: 13–30)	-	-
W.V. Genechten et al.	2022	Numeric rating scale (NRS) e knee injury and osteoarthritis outcome score (KOOS), e UCLA activity score	The NRS pain score decreased from 6.1±1.9 at baseline to 2.9±2.3 per year. KOOS outcome was 31.4±17.6 preoperatively and increased to 70.2±15.0 at one year after operation (p<0.001) Baseline UCLA activity score was 5.7±2.3, which increased to 7.6±2.2 at one year (p=0.002)	X-ray, CT	Beginning to advanced bone graft incorporation was observed three months after surgery on CT-scan while all osteotomies were consolidated at one year on plain radiographs. Five patients had their implants removed within the first year (7.8 months±3.6) for local irritation.

The main advantage of this systematic review lies in the strict adherence to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol and the use of precise inclusion and exclusion criteria. These factors made our study more dependable, as we carefully examined all the most recent scientific data on this topic.

Our systematic review has several limitations. First, only specific studies (original articles published in English) have been included in this review. This may have resulted in our omission of other high-quality literature from other languages. Additionally, due to the limited number of articles addressing the specific topic of interest to our research, we had to include articles from various formats and compare clinical case descriptions and cohort studies based on subgroup analyses.

Third, the duration of the observations varied in different studies, which could lead to biased results.

This is because despite the high level of use of 3D printing in orthopedic practices and the extensive global experience with allografts, its combined use is only just beginning to be developed. This not only determines the relatively small number of studies on this topic but also represents an exciting potential for the direction we have chosen.

The research team's interest in this area is driven not only by the novelty and innovation of the symbiotic relationship between the two topics under discussion. Of far greater significance, both for scientific and clinical purposes are the flexibility, accessibility, and high accuracy of 3D printing technology in most clinical settings in developed countries. Due to the benefits of adequate preoperative planning, more accurate intraoperative procedures, and the use of customized instruments and surgical guides, it is now possible to achieve successful outcomes in complex cases involving extensive bone defects, severe orthopedic deformities, and comminuted fractures.

Nevertheless, many problems associated with the use of additive technologies in orthopedic surgical practice need to be solved in the future. Larger multicenter randomized controlled clinical trials are needed in the future to study the effects of 3D printing on revision total hip and knee surgery.

Conclusion

Today, there is an increasing focus on comparing 3D printing with allotransplantation in orthopedic applications. This review has demonstrated that in most cases, the symbiosis between these techniques consists of tailored guides for more precise excision of defects or corrective osteotomies, using similar tailored guides to produce allografts of the desired shape. This challenging but promising step allows orthopedic surgeons to build upon existing work and conduct multicenter research in this area. Certainly, the integration of additive technologies with bone allotransplantation has great potential for complex orthopedic cases and can certainly be recommended for widespread adoption in global practice.

Competing interests. The authors declare that they have no competing interests.

Funding. Funding help during the research was made by Karaganda Medical University.

Authors' contributions. M.B. and A.K. made a selection from data bases and exclusion by PRISMA 2020 recommendation. M.D. made an analysis of demographic data, including Coleman Methodology Scale. M.A. analysed outcomes in selected articles. B.T. summarized tables from both reviewers. Also B.T. was an independent reviewer during the all process of research when it was some disputs. All authors reviewed the manuscript.

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Ортопедиялық тәжірибеде сүйек трансплантациясын аддитивті технологиямен бірге қолдану

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Түйіндеме

Ортопедиялық хирургияда сүйекті қалпына келтіруге арналған материалды таңдау мәселесі өзекті болып қала береді және технологиялық жетістіктермен қатар дамып келеді.

Бұл шолу ортопедияның салыстырмалы түрде жаңа аспектілерінің бірін, атап айтқанда сүйек трансплантациясын 3D технологиясымен бірге қолдануды талдауға бағытталған. Әдебиеттерді іздеу қазіргі заманғы өзекті Еуропалық және Американдық медициналық деректер базаларын пайдалана отырып жүргізілді. Барлық іздеу нәтижелері тіл және 2014-2024 жылдар кезеңі бойынша сүзілді. Содан кейін түйін сөздер бойынша 10000-нан астам мақала болды, ал алып тастағаннан кейін 10 мақала қалды. Когорттық зерттеулерді талдау үшін біз демографиялық деректерді, клиникалық және радиологиялық нәтижелерді талдау үшін әрбір зерттеу үшін Coleman әдіснамасының масштабын және кестені қарауды қолдандық. Зерттеудің әртүрлі түрлері болды, соның ішінде клиникалық жағдайды зерттеу, ретроспективті когортты зерттеу және перспективалық когортты зерттеу. Қарастырылған барлық мақалаларда рентгенологиялық нәтижелер және емдеуден кейінгі 4 клиникалық нәтижелер келтірілген.

Зерттеу нәтижелері таңдалған тәсілдің әлеуетін көрсетті. Дегенмен, қазіргі уақытта тиісті тақырып бойынша, тіпті клиникалық жағдайлардың сипаттамаларын қоса алғанда, салыстырмалы түрде аз жарияланған жұмыстар бар. Әрине, аддитивті технологияларды сүйектерді аллотрансплантациялаумен біріктіру күрделі ортопедиялық жағдайларда үлкен әлеуетке ие және оны әлемдік тәжірибеде кеңінен енгізу үшін ұсынуға болатыны рас.

Түйін сөздер: сүйек кистасы, 3D басып шығару, сүйек ақауы, сүйек аллографы, аллографт, аддитивті технология.

Использование костных трансплантатов в сочетании с аддитивными технологиями в ортопедической практике

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Абстракт

Вопрос выбора материала для реконструкции костной ткани в ортопедической хирургии остается актуальным и продолжает развиваться в соответствии с технологическими достижениями.

Цель данного обзора — проанализировать один относительно новый аспект ортопедии, а именно комбинированное использование костных трансплантатов с 3D-технологиями.

Был проведен поиск литературы с использованием современных европейских и американских баз медицинских данных. Все результаты поиска были отфильтрованы по языку и периоду с 2014 по 2024 год. По ключевым словам было найдено более 10 000 статей, и после тщательной выборки осталось 10 статей. Для анализа когортных исследований мы использовали шкалу методологии Коулмана и просмотр таблиц для каждого исследования с целью анализа демографических данных, клинических и радиологических результатов. Были представлены различные типы исследований, в том числе клиническое исследование случая, ретроспективное когортное исследование и проспективное когортное исследование. Во всех рассмотренных статьях представлены радиологические результаты, а в четырех — клинические результаты после лечения.

Результаты исследования продемонстрировали потенциал выбранного подхода. Однако в настоящее время опубликовано относительно небольшое количество работ по этой теме, включая даже описания клинических случаев. Безусловно, интеграция аддитивных технологий с аллотрансплантацией костной ткани имеет большой потенциал для сложных ортопедических случаев и может быть рекомендована для широкого применения в мировой практике.

Ключевые слова: костная киста, 3D печать, костный дефект, костный аллографт, аллографт, аддитивные технологии.