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THE USE OF 3D PRINTING FOR PREOPERATIVE PLANNING AND INDIVIDUALIZATION OF TREATMENT IN TRAUMATOLOGY AND ORTHOPEDICS: CONCEPTUAL EVOLUTION AND DEVELOPMENT PROSPECTS

3D printing technology in orthopedic surgery and traumatology opens up wide opportunities for improving preoperative planning and personalization of treatment, which leads to an improvement in the quality of medical care. This review focuses on modern advances in the use of 3D printing to create models, implants, and instruments that adapt to the individual anatomical characteristics of the patient. The benefits of 3D printing include improving the accuracy of surgical procedures and reducing operational risks through personalized solutions. At the same time, the review highlights key obstacles to the introduction of technology into clinical practice, such as high costs and the need for standardization of processes. Despite these challenges, 3D printing has significant potential to transform medical approaches and teaching methods, which opens up prospects for creating more effective and personalized therapeutic techniques in the field of orthopedics and traumatology.

Keywords: orthopedic surgery, 3D printing, traumatology, implants, 3D modeling, surgical instruments.

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Introduction. Three-dimensional (3D) printing, also known as additive manufacturing or rapid prototyping, has been around for several decades and is recognized as an effective method of manufacturing orthopedic instruments and implants [63,35,53]. In recent years, interest in 3D printing in the field of orthopedics has grown again, due to cost reductions, increased availability of 3D printers, printing materials and software, as well as the desire to provide more personalized treatment to patients. This development has led to the concept of "local printing" or "on-site printing of medical care" (PPC). Regardless of who manufactures the devices, traditional companies or PPC, the advantages of 3D printing are obvious. [46, 31, 16, 36].

This technology makes it possible to develop instructions and surgical instruments adapted to the specifics of each individual anatomical model, which makes it possible to perform volumetric and accurate 3D measurements [38]. Individualized instruments help surgeons simulate operations, accurately measure necessary adjustments in osteotomy, plan fracture repair, calculate the volume of required allografts, and apply this technology in many other fields [25]. The purpose of this review is to present an approach to understanding this technology and its key principles.

Materials and methods. A literature search was conducted in the following databases: Web of Science, Scopus, PubMed (MEDLINE), eLibrary.RU and Cochrane Database of Systematic Reviews. Keywords such as "3D printing in orthopedic surgery", "three-dimensional printing and traumatology", "additive manufacturing in orthopedics", "personalized implants in traumatology", "3D printing and surgical instruments", "internal printing and medical care" were used to select relevant publications.

As a result of the search, 5005 publications were found. After removing 1,702 duplicates, the selection process was continued with 3,303 potentially suitable studies. When checking the titles and annotations, 3089 articles were excluded. The full texts of the remaining 214 articles were analyzed in detail, and the final list included 64 works. The PRISMA block diagram is shown in the figure (Figure).

In the table (table.1) All demographic and technical data are listed. Among the 64 selected studies, both randomized controlled trials, meta-analyses, and systematic reviews were reviewed. Special attention was paid to the quality of the methodology and the approaches used in the research. The obtained results allowed us to draw reasonable conclusions about the influence of the studied factors, as well as to identify areas requiring further research.

Historical background. The origins of three-dimensional printing can be traced back to the time when the art of sculpture was born in the Stone Age. Humanity, existing in a three-dimensional world, has always sought to reproduce this reality in different materials. In 1859, Francois Willem created the first 3D scanning technology in France, calling it "photosculpture." Photographs taken with a 360-degree viewing angle were used to create silhouettes of a person or object, which were then transferred to the desired scale thanks to the pantograph and served as the basis for creating a three-dimensional sculpture. In 1892, Joseph Blanter patented in the United States a technology for creating three-dimensional topographic maps that used a layer-by-layer accumulation method similar to the concept of modern 3D printers. Almost a hundred years later, in Japan, Hideo Kodama proposed the idea of creating 3D prototypes by injecting photopolymers that harden under the influence of ultraviolet rays. However, the first person to create a real 3D printer was Charles Hull in 1984 in the USA, and he is considered the founder of 3D printing [61]. In 1988, Hull introduced the first 3D printer on the market, called the SLA-250 [33].

Since 2007, patents have been issued, and interest in the topic of 3D printing has increased markedly. Affordable, open-source printers were developed that could self-replicate. The first mention of the use of this technology in the healthcare sector appeared at the beginning of the 21st century [35, 44]. In the period from 2009 to 2011, there was a change of emphasis in publications: from simple printing for preoperative planning to the production of surgical instruments and even implants [63].

The use of 3D printing in orthopedic surgery and traumatology. All over the world, orthopedic surgeons, specialists in related fields and scientists are actively using 3D printing to create models, instruments, implants, orthoses and prostheses adapted to each patient. 3D bioprinting technologies are also used to create skeletons of bones and cartilage, covering almost all aspects of orthopedic traumatology, from the head to the feet (Table 2).

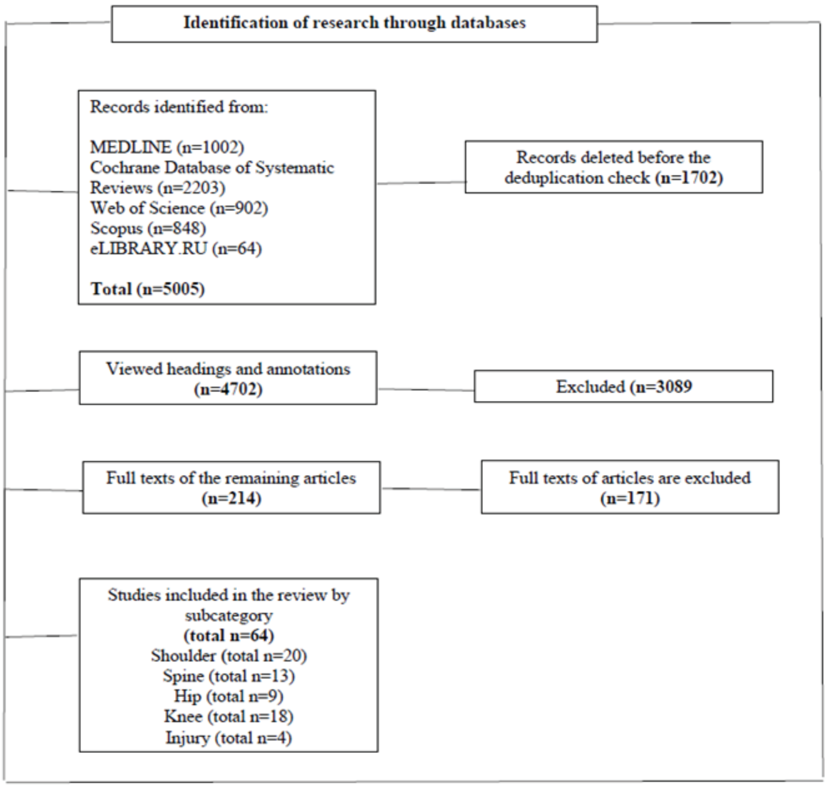
Based on the presented table, we note that the use of 3D models allows surgeons to visualize complex anatomical structures in advance, such as the proximal humerus, acromion, and pelvis, which contributes to more accurate and efficient operations. In particular, for the distal humerus and elbow, printing plates, templates and guides optimize the surgical process, increasing its predictability and reducing the risk of complications. Personalized navigation templates for ankle ligament repair improve the results by taking into account the individual anatomical features of the patient. In addition, 3D printing technologies promote innovations in reconstructive approaches, as in the case of the hand and thumb model, which opens up new possibilities for restoring the functions of complex joints and bone structures. In general, the use of 3D printing in orthopedics contributes to improving the quality of medical care, reducing operational risks and improving patient rehabilitation.

The main advantages and disadvantages of 3D printing in orthopedic surgery and traumatology. Orthopedics and traumatology are among the medical fields where 3D planning has significantly influenced practice, especially in the treatment of injuries and oncological orthopedics. An analysis of the literature in the field of orthopedics shows a noticeable increase in the number of publications devoted to this topic [55, 24, 25, 20, 12]. The main use of 3D technologies is related to preoperative planning, as well as the development of individual implants and guiding devices. Among the most commonly used materials for 3D printing are titanium, acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA).

In preoperative preparation, 3D printing opens up new possibilities for improving accuracy that are unattainable using traditional methods. This is especially true for the treatment of fractures, where it is important to model the recovery process in advance. Significant improvements have been noted in studies such as the work of Izatt and his colleagues: surgeons indicated that in 65% of cases anatomical details on biomodels were more noticeable than with standard visualizations, and in 11% they were unique only to 3D models [57]. These achievements emphasize the importance of 3D modeling, since improving the understanding of anatomical structures can directly affect the choice of materials and the location of implants, which is confirmed by the research of Wu and Shao [54].

Continuing the topic of precision, the research of Iannotti and co-authors demonstrate that the use of individual instruments in orthopedics, for example, in shoulder replacement, significantly improves the positioning of components [59]. Other papers, such as the Buller study, describe how arthroplasty guides allow experienced surgeons to reduce orientation deviations by 9 degrees, thereby increasing the accuracy of operations [56].

The integrated use of 3D printing and computer navigation complements procedures, as shown in the Chen study: the use of these technologies improved the accuracy of implant placement during reconstructive operations on pelvic bones by 3-5 times [23]. This also led to a reduction in radiation exposure and blood loss, which was noted during bone surgeries such as calcaneal and tibial.



Preferred reporting elements for systematic reviews and meta-analyses (PRISMA)

One of the biggest advantages of 3D technology remains personalization. Dekker and colleagues emphasize that individual implants based on precise parameters of the patient's anatomy significantly improve treatment results, for example, in complex deformities of the foot [39]. In addition, the prospects of bioprinting open up new horizons in the creation of biomaterials for tissue regeneration, as indicated in the works of Tan and co-authors [53]. As can be seen from these advantages, 3D printing technology is transforming orthopedics and traumatology, enabling precise preoperative planning and the creation of customized surgical instruments and implants, which significantly increases the accuracy and effectiveness of procedures.

However, despite the significant advantages, the use of 3D printing in medicine is fraught with certain difficulties that must be taken into account for the successful integration of this technology into medical practice [61, 25]. The disadvantages of 3D printing are similar to the disadvantages of any innovative technology, including high costs and lack of data, which is especially important in the economically limited and controversial field of medicine, where customized medical implants are manufactured. In addition, considerable time and resources are required to train medical professionals to use this technology in practice. Standardization and regulatory issues also require special attention to ensure the safety and effectiveness of the products [60].

Despite these challenges, the continued improvement of 3D technologies and the accumulation of experience in their application promise significant improvements in the quality of medical care and expanded treatment options, making the future of medicine more personalized and effective.

Application of additive 3D printing technologies in the diagnosis and treatment of pathologies of the musculoskeletal system. The use of additive 3D printing technologies for the diagnosis and therapeutic intervention in various pathologies of the human musculoskeletal system, including fractures, bone neoplasms, arthrosis of large joints, as well as congenital and acquired deformities and other conditions.

One of the most urgent tasks of modern medicine is the treatment of patients with bone diseases. The inci-

Table 1

Demographic and technical information on research using 3D printing in orthopedic surgery and traumatology

Link	Country	Category	Visualization method
Parratte et al. [31]	USA	Spine	CT
Gauci et al. [46]	France	TSA	CT
Wang et al. [16]	China	THA	CT
Yamamura et al. [43]	Japan	TKA	CT
Ferretti et al. [55]	Italy	THA	CT
Hendel et al. [24]	USA	TSA	CT
DeVloo et al. [58]	Belgium	TKA	MRT
Sariali et al. [50]	France	TKA	CT
Cui et al. [32]	China	Spine	CT
Roh et al. [38]	South Korea	TKA	CT
Dasari et al. [13]	USA	TSA	CT
Mohar et al. [47]	Slovenia	Spine	CT
Van Genechten et al. [36]	Belgium	TKA	CT
Matsukawa et al. [41]	Japan	Spine	CT
Moya et al. [64]	Mexico	TSA	MRT
Zheng et al. [25]	China	TKA	CT
Zhang et al. [30]	China	Pelvic area	CT
Chen et al. [23]	China	Spine	CT
Cho et al. [15]	South Korea	Spine	CT
Zheng et al. [18]	China	Pelvic area	MRT, CT
Rosenzweig et al. [14]	Canada	TSA	CT
Pehde et al. [29]	USA	TKA	CT

Note* CT - computed tomography; MRT- magnetic resonance imaging; THA - total hip replacement; TKA - total knee replacement; TSA - total shoulder replacement.

dence associated with both primary bone tumors and metastases to the musculoskeletal system is increasing annually. More than 2,900 cases of cerebral palsy and previously diagnosed osteogenic sarcomas are registered annually. In addition, many malignant neoplasms are prone to metastasis to bone tissue. In a study conducted on the basis of the Volga Scientific Research Medical University of the Ministry of Health of Russia, the results of surgical treatment of 22 patients with tumors of the long bones of the upper extremities were analyzed. After the tumors were removed, all patients underwent simultaneous bone transplantation. To eliminate the defects, individual implants made of bone replacement material using 3D printing technologies were used.

In the postoperative period, all patients noted a decrease in pain and an improvement in the function of the upper extremities. During the entire follow-up period, there were no X-ray confirmed cases of implant displacement. A year after surgery, patients with benign tumors showed the following results: according to the SF-36 questionnaire, the average score was 71.4 ± 6.6, according to the visual analog scale (VAS) - 2.5 ± 1.5 points, and according to the MSTS scale (Society's assessment of Tumors of the Musculoskeletal System) — 65.1 ± 8.3%. In patients with malignant changes, the indices were: SF-36 — 39.2 ± 4.3 points, VAS — 4.8 ± 1.4 points, and MSTS — 41.8 ± 5.2% [3].

The study conducted by Berasi C.C. and co-authors examines the experience of using individual titanium hip cups created using a 3D printer in revision arthroplasty in patients with critical bone loss. The authors analyzed 28 operations performed in 26 patients, among which 4 patients needed repeated revisions. The causes of unsuccessful outcomes were 2 cases of periprosthetic infections, 1 case of loosening of the femoral component of the endoprosthesis and 1 case of fracture of the prosthesis [20].

The individual implants demonstrated good durability, with no signs of migration or weakening over an average follow-up period of 2.5 years. The researchers concluded that the results of using the implants are comparable to the use of anti-intrusive cells and extension cords. In cases of significant damage to the acetabulum accompanied by pelvic dissociation, the use of individual implants may be more effective [12].

The positive results of patient treatment were also noted in a study evaluating the use of individualized guides for positioning during resection, created using 3D printing and prototyping. The authors showed that operative planning using these individual guides and physical modeling of the tibia and femur leads to a statistically significant normalization of the axis of the lower extremities in all patients. Applications of individual guides include cases with a history of inflammatory diseases or deformities, as well as the need for hip or hip replacement. Their use may be preferable when it is necessary to avoid opening the bone marrow canal. This is especially true in the presence of massive bone defects, large osteophytes in the posterior condyles of the femur, or with pronounced restriction of movement in the knee joint [5].

Table 2

Results of 3D printing application in various fields of orthopedic surgery and traumatology

Anatomical area	Applications of 3D printing
The proximal humerus	A 3D model used for planning [64]
Acromion	A 3D model used to adjust the shape of the plate [25]
Collarbone	A 3D model designed for planning and preparing plates [61]
Distal humerus and elbow	Plates for 3D printing, 18 templates and guides, as well as 3D models [61]
Distal radius	Surgical planning of osteotomies using 3D modeling [25]
Arm	Experimental 3D modeling for planning thumb reconstruction, including vascularized bone flaps and navicular plates [64]
The basin	A 3D model used for preparation and planning [61]
Distal femur	A 3D model used for preparation and planning [61]
ACL Reconstruction	An arthroscopic instrument for creating the femoral tunnel of the ACL, adapted to the ethnic characteristics of the patient based on MRI data [25]
Proximal tibia	A 3D model used for preparation and planning [61]
Tibial pylon and ankle	A 3D model used for preparation and planning [61]
The ankle	Personalized navigation template for ankle ligament repair [64]

The number of applications of additive technologies, such as 3D printing, is increasing annually in the field of creating individual orthotics and orthopedic insoles. In the study [10], methods for the production of such insoles using 3D printing were developed. The researchers successfully achieved their goals and demonstrated that a statistically significant improvement ($p < 0.05$) was recorded not only according to the AOFAS questionnaire, but also according to the results of biomechanical examinations of patients. In addition, the use of custom-made orthopedic insoles using 3D printing has shown that they help to restore the load on the lower extremities, reduce pain and bring gait closer to the physiological norm, contributing to improving the quality of life of patients [10].

The study by Karyakin N.N. and Gorbatov R.O. [3] presents the results of the development of technologies for creating individualized orthoses for immobilizing joints of the upper extremities using 3D printing. This technology includes measuring the biometric parameters of the corresponding area and determining the necessary force for immobilization, on the basis of which a 3D model of the orthosis is created. The subsequent production process is carried out using an FDM 3D printer. The created orthoses have demonstrated high efficiency in immobilization, providing excellent radiological and clinical treatment results. They have a number of advantages over traditional manufacturing methods: individual adaptation depending on the biometric parameters of the patient and the type of pathology, light weight, fast application, resistance to moisture and heat exchange between the damaged area and the environment [11].

Despite the positive results of the application, the local implementation of additive technologies faces a number of difficulties related to the complexity of the technological processes themselves [1]. First, there is the high cost of 3D printing equipment and supplies, which can be a significant barrier for small medical facilities and laboratories. Secondly, the technology itself requires specific training from specialists and the ability to work with digital models and programs that prepare data for the printer. Thirdly, standards and protocols for the use of additive technologies in medicine are still insufficient, which makes it difficult to integrate these technologies into everyday medical practice.

Nevertheless, the experience of using polymer models of the pelvis is actively discussed in the scientific literature on pelvic bone fractures. These models play a key role in preoperative preparation, allowing surgeons to carry out rational planning and preliminary modeling of surgical plates. This makes it possible to reduce risks and improve the results of operations [11].

In turn, the research led by Cai L. and his co-authors demonstrate that the inclusion of 3D models in the preoperative planning process significantly reduces both the radiation load and the duration of the operation. This is especially important when performing minimally invasive vascular osteosynthesis, which is necessary to correct unstable fractures [12].

After analyzing publications on 3D technologies, Krettek C. and Bruns N. also came to the conclusion that the level of evidence of these works is low and contains many methodological shortcomings, such as limited samples of clinical examples and lack of long-term efficacy data [40]. Nevertheless, they emphasize the importance of the research conducted, as additive technologies offer enormous potential for the medical industry, opening up opportunities for personalized medicine and improving the effectiveness of surgical interventions.

Customized tools created by 3D printing. The PSI concept, or tools adapted to each patient, is actively used in scientific publications and research. In the world literature, it is customary to designate this area with a term reflecting an individualized approach to medical procedures. These dual devices are being developed on the basis of data obtained from computer models, which significantly improves the efficiency of their use.

With the use of 3D printing technology, such instruments become an integral part of surgical operations, providing a more rational intervention to increase accuracy. This becomes especially important in the context of oncoortopedic operations, where a high degree of accuracy and adaptability is required.

The term PSI refers to a unified concept encompassing special surgical instruments, including templates and manuals that are widely used in the planning and execution of medical procedures. In some situations, however, it may be necessary to perform radical resection of the tumor, which requires the use of more aggressive surgical methods.

In his study, Buller L. and his colleagues are comparing two control groups of patients. In one group, the installation of the swivel component was carried out using the standard method. In the second group, PSI technologies were used, which provide an individual approach and increase the accuracy of the installation [56]. The results showed that in patients whose treatment included the use of PSI, the average deviation of angles such as anteversion and tilt was significantly smaller, indicating a more optimal displacement of the components. This confirms the effectiveness of PSI not only in hip replacement, but also in more complex operations such as the installation of transpedicular screws in the spine, where precision and individual approach are important.

PSI technologies are actively used for radical resections in the treatment of malignant tumors in the pelvic bones [34]. François Gouin and his team performed pelvic bone tumor removal in 11 patients using PSI [28]. After the operations were completed, a histological examination of the removed tissue was performed. Macroscopic analysis and comparison of postoperative CT images with preoperative CT data made it possible to evaluate the accuracy of performed surgical interventions. The results showed that in all cases, the edges of the resections were classified as R0, which confirms the complete removal of the tumor tissue. At the same time, the average accuracy of resection, determined by comparing X-ray images, was 2.5 mm.

Individual navigation templates for installing transpedicular screws in the cervical spine. In recent years, the number of publications on the use of transpedicular fixation in the cervical spine has increased significantly. This is explained by the fact that from a biomechanical point of view, this technology demonstrates exceptional stability and, in some cases, may be the only effective method of correcting pathologies [45, 28, 37]. In response to the current need, alternative methods have emerged, such as the use of new surgical technologies in spinal neurology. One of such innovative approaches is the development of individual navigation templates created using 3D printing, which allow precise installation of implantable screw structures [23, 55].

There was also interest in this area in the Russian Federation: the first mention of the methodological approach was presented at a conference in 2018, where a clinical case of a patient with C2 vertebral neoplasia was considered [4]. Continuing to study this issue, in 2019, Kovalenko R. A. and his colleagues published a study discussing the use of templates for installing transpedicular screws in the subaxial and upper thoracic spine [6]. They reported that out of 88 installed screws, the accuracy of compliance with Class 1 and 2 was 97%. In addition, implantation safety level 0 was achieved in 79 cases (89.77%), level 1 in 5 cases (5.68%) and level 3 in 2 cases (2.27%).

Earlier, in 2015, Abumi K. and his colleagues demonstrated the successful implementation of this technique by installing 80 transpedicular screws in the subaxial cervical spine using three types of individual 3D navigation matrices for each vertebra. These matrices provided accurate identification of entry points, drilling direction, and navigation when installing screws [26]. Of the 80 installed screws, 78 turned out to have a safety level of 0. It was also noted that the absence of the need for retraction of the paravertebral muscles in the middle part of the cervical region allowed the use of additional instruments for the removal of soft tissues [34].

However, several researchers point out potential errors related to the insufficient accuracy of adapting the navigation pattern to the spine [4]. Especially in the subaxial region, where a significant angle of convergence may require an additional incision to ensure the correct direction of the tool. Sometimes it is also necessary to modify a part of the navigation template in order to successfully install the screws on the opposite side [48].

Thus, innovative approaches in 3D navigation and customized templates significantly improve the accuracy and safety of transpedicular screw implantation in difficult cases. However, further research and technology improvements are needed to minimize possible errors and expand their application in clinical practice.

The use of navigation guidance templates in the field of orthopedics. In recent years, advanced technologies in the field of orthopedics have been developed and actively applied, expanding the capabilities of surgeons in the treatment of spinal diseases. One of these methods is the use of navigation guidance patterns, which significantly improve the accuracy of implant placement. These patterns are especially important in cases such as the correction of scoliosis in children, where the accuracy and safety of the procedure are crucial [4, 2].

An analysis of the use of guiding navigation patterns in the field of orthopedics shows how transspedicular fixation is becoming the main method of surgical stabilization of the spine. In a study conducted by A.V. Kosulin and his colleagues, the use of individual navigation patterns for installing transpedicular screws in children with spinal deformities was studied. The study showed that 3D models were created on the basis of preoperative computed tomography, according to which polylactide (PLA) navigation templates were developed and manufactured on a 3D printer [7]. During the operations, templates were used to accurately position the screws. The results showed that 93.7% of the screws were installed with high accuracy inside the bone, confirming the effectiveness and safety of the method. The use of this method allows not only to improve the stability and effectiveness of surgical interventions, but also to significantly speed up the recovery process of patients. This technology opens up new possibilities for individualizing treatment and optimizing surgical procedures in pediatric orthopedics.

Complementing these findings, the authors Kokushin D.N., Vissarionov S.V., Baindurashvili A.G. and colleagues conducted a study evaluating the use of guiding templates (SHN) for the installation of transpedicular screws (TV) in children with congenital scoliosis. The second version of the monosegmental SHN proved to be the most effective, which ensured the correct installation of 93.7% of the screws. This made it possible to increase the accuracy of the procedure and minimize the risks of malformation, without the occurrence of neurological disorders in the postoperative period. The authors emphasized the importance of taking into account anatomical and morphological features when planning the installation of TV in children [8].

It should be noted that the publication by Kovalenko R.A. and co-authors focused on the use of individual navigation patterns for installing screws in the subaxial cervical and upper thoracic spine. The study determined the risk of implantation, while in 79 cases (89.77%) the screws were installed without deviations (grade 0), in 5 cases (5.68%) there was a slight deviation (grade 1), and in 2 cases (2.27%) serious deviations (grade 3) were detected. The matrix was designed taking into account three points of contact on the arches of the vertebrae and joints, as well as on the spinous process, with the guide tubes fixed with stiffeners. The channel for installing the screw was formed by means of a drill bit or a Kirchner wire, which was guided through the tube. The development and application of such matrices can significantly reduce the risk of implantation errors, which is of key importance for increasing the safety and effectiveness of surgical intervention [6].

Discussion. The use of 3D physical models in medical practice provides a number of advantages over traditional imaging techniques such as CT and MRI, as well as virtual reconstructions. For example, studies by Auricchio and Marconi confirm that three-dimensional printing is actively being implemented in orthopedics and traumatology to improve preoperative planning and modeling of complex anatomical structures [21]. This is consistent with our findings that physical models can reduce errors caused by a limited understanding of volume, viewing angle, and lighting when working with two-dimensional images.

The study by Sheth and colleagues pays special attention to the use of 3D printing as part of preoperative planning for shoulder joint instability [51]. This correlates with our observations that physical models help surgeons more accurately assess anatomical abnormalities, for example, when correcting hip joint deformities and other complex interventions. Other studies, such as the work of Mazzarese and colleagues and Smoczok et al., note the potential of 3D printing in implant modeling and the development of retainers made of absorbent polymers, which proves the possibility of improving surgical correction and adapting instruments to the individual needs of the patient [42, 52]. Finally, the work of Trauner [62], Kang and colleagues [22] emphasize that 3D printing not only changes the approach to surgical intervention planning, but also promotes training and improves the skills of novice surgeons, which is also one of the key conclusions of our study. Overall, a variety of research shows that 3D printing has significant potential to transform orthopedic practice and education.

Thus, in the field of orthopedics and traumatology, 3D printing technology allows surgical procedures to be planned in advance, this possibility can lead to improved intervention results and shorter surgery time. 3D-printed models can be a useful tool for training aspiring surgeons, improving the quality of training and speeding up the learning process.

Conclusion. An analysis of the scientific literature has shown that the use of 3D printing in orthopedic surgery and traumatology opens up new horizons for individualizing treatment and improving the quality of medical care. The technology promotes more accurate preoperative planning, allows you to create models and tools adapted to the patient, which reduces operational risks and improves the results of operations. However, for the successful integration of 3D printing into clinical practice, it is necessary to overcome a number of challenges, including high costs, the need to train specialists and the development of standards. Despite these obstacles, the continued improvement of technologies and the accumulation of experience in their application can significantly improve the effectiveness and personalization of medical interventions, making future medical practices more accurate and safer.

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CAPILLAROSCOPY AS A METHOD OF DIAGNOSTICS OF SYSTEMIC DISEASES IN CHILDREN

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The article presents current data on the possibility of using capillaroscopy as a method of diagnostics of systemic diseases. Capillaroscopy can be widely used in pediatrics due to the following advantages: simplicity, non-invasiveness, relatively low cost, and possibility of repeated examination.

Keywords: capillaroscopy, microcirculation, pediatrics, rheumatology, systemic connective tissue diseases, Raynaud's syndrome, systemic scleroderma, juvenile dermatomyositis.

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Capillaroscopy is a noninvasive method of microcirculation examination based on visualization of capillaries through the skin, which plays a key role in the differential diagnosis of primary and secondary Raynaud's phenomenon, and has been successfully used for diagnosis of diseases such as systemic scleroderma, juvenile dermatomyositis. It can also be used for their staging and activity assessment. Capillaroscopy can also be useful for evaluating the microcirculation in other rheumatic diseases such as systemic lupus erythematosus, antiphospholipid