doi: 10.21823/2311-2905-2020-26-3-170-181

The Effectiveness of Various Surgical Techniques in the Treatment of Local Knee Cartilage Lesions (Review)

T.A. Kulyaba [1], S.A. Bantser [1], P.A. Trachuk [2], T.N. Vorontsova [1], N.N. Kornilov [1, 3]

[1] *Vreden National Medical Research Center of Traumatology and Orthopaedics, St. Petersburg, Russian Federation*

[2] *Pavlov First Saint-Petersburg State Medical University, St. Petersburg, Russian Federation*

[3] *Mechnikov North-Western State Medical University, St. Petersburg, Russian Federation*

Abstract

Background. A large number of surgical methods are used in clinical practice to treat the limited lesion of the knee cartilage: isolated affected area debridement, stimulation of chondrogenesis, mosaic osteochondral repair, cell technologies, collagen membranes (matrices), and the combination of the above techniques. ***The purpose of this review*** – to compare the effectiveness of various surgical treatments for the limited lesion of the knee cartilage based on the content analysis of publications. ***Materials and Methods.*** The review includes 85 papers for the period from 2005 to 2020. The search was carried out in electronic scientific databases PubMed and eLIBRARY. ***Results.*** In the medium and long term, debridement and/or various options of chondrogenesis stimulation are clinically, radiologically and histologically inferior to all other surgical techniques, despite their wide popularity. Mosaic osteochondral auto- and allograft transfer, as well as transplantation of autologous chondrocytes culture with a collagen membrane, are characterized by the best 15 to 20-year outcomes, allowing most patients to maintain the same level of activity as it was before the trauma. The combination of matrices with other cellular products or microfracturing shows the similar mid-term results, but their long-term efficacy remains unknown. ***Conclusion.*** The use of debridement and/or chondrogenesis stimulation should be limited to the defects with the minimal area. Mosaic osteochondral graft transplantation is the optimal treatment method for cartilage lesion of up to 4 to 6 cm2 both from a clinical and economic point of view. The combination of membranes with various cellular products or microfracturing is indicated in case of extensive lesions or when the mosaic osteochondral graft transplantation is impossible

Keywords: knee, limited cartilage lesion, microfracturing, collagen membranes.

Local cartilage lesion (LCL) of the knee, or chondromalacia, is the disruption of the joint cartilaginous cover integrity resulting from injuries or diseases. Such a lesion is limited mainly to one area of the joint, extending to the depth of the articular cartilage or reaching the subchondral bone. There is no generalized degenerative-dystrophic joint disease.

Chondromalacia was first described by K. Budinger in 1906. The term itself was used by O. Aleman in 1928 [1].

According to foreign authors, LCL is diagnosed both in isolation and in combination with other pathology in 30 to 60% of the patients during knee arthroscopy. Moreover, in 65% of cases, it is combined with meniscus pathology [2, 3, 4, 5].

Cite as: Kulyaba T.A., Bantser S.A., Trachuk P.A., Vorontsova T.N., Kornilov N.N. [The Effectiveness of Various Surgical Techniques in the Treatment of Local Knee Cartilage Lesions (Review)]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2020;26(3):170-181. (In Russian). doi: 10.21823/2311-2905-2020-26-3-170-181.

Sergei A. Bantser; e-mail: serg249_spb@mail.ru

Received: 10.07.2020. Accepted for publication: 28.07.2020.

A. Aroen et al., analyzing the results of 1000 knee arthroscopies, found that in 11% of the patients there were full-thickness cartilage lesions required the surgical treatment. In 55% of the observations, the lesion area exceeded 2 cm^2 [6].

Approximately 200,000 surgeries for cartilage lesion are performed in the United States annualy. That means that the requirement ratio is 614 per 1 million people. The number of such surgeries is increasing by about 5% every year [7]. If the specified coefficient of demand is applied to the number of residents of the Russian Federation, the need for such surgeries can be up to 90,000 per year. It should be emphasized that taking into account social conditions, sports priorities and other features, this figure should be regarded as very approximate.

The low regenerative potential of hyaline cartilage is due to the peculiarities of its histological structure. This, in turn, leads to the early progressive development of total degenerative-dystrophic joint lesion, even when the affected area is limited [8, 9]. The degree of the degenerative process progression of the morphologically comparable osteochondral knee lesions in the long term (over 6 years) in the patients received the conservative treatment was significantly more pronounced compared to the patients undergone the surgery [10].

Scientific and clinical interest in the problem of choosing the optimal method of LCL surgical treatment is confirmed by an increase in the number of publications devoted to the issue in the special literature, but a consensus has not been reached to date [11, 12]. The high incidence of LCL, especially of the femoral condyles, the absence of a standardized algorithm for surgical treatment choosing, and suboptimal long-term results of a number of currently using methods served as the reason for writing this review.

The purpose of this review – to compare the effectiveness of various surgical techniques for the treatment of limited lesion of the knee cartilage based on the content analysis of publications.

Materials and Methods

We searched for scientific publications on surgical methods for the treatment of the femoral condyles LCL in the electronic databases PubMed and eLIBRARY for the period from 2005 to 2020. Also, the review included a number of earlier fundamental scientific studies of the late XX-early XXI centuries on the topic and were fundamental in the development of a particular method of LCL treatment. The search was carried out using the following keywords: cartilage damage, chondral defect, osteochondral lesion, osteochondritis dissecans, Koenig disease, knee joint. As a result of the search, 85 (6 domestic and 79 foreign) relevant to the topic of the review publications were selected.

Results

The goal of LCL treatment is to replace the defect with the tissue with its mechanical properties closer to hyaline cartilage. In clinical practice, various methods of treatment are used, which can be divided into the following groups [13, 14]:

– debridement of the lesion area (removal of unstable cartilage and bone fragments, smoothing irregularities on the cartilage and bone surface);

– stimulation of chondrogenesis, that is, assistance in the restoration of a lesion by the formation of a blood clot with multipotent mesenchymal stem cells (MMSC) from the bone marrow migration into it. These cells are capable to differentiate into chondroblasts (tunneling, the technique of microfractures creation, spongialization or abrasive chondroplasty which is the resection of subchondral bone plate);

– implantation of tissues containing chondrocytes or cells capable of chondrogenesis – transplantation of bone-cartilage allo- and autografts: (mosaic bone-cartilage auto-/alloplasty (OATS), osteochondral au-

tograft transfer system (OATS, mosaic plasty), cultures of autochondrocytes implantation (ACI, MACI), MMSC;

– a combined technique (membrane + microfractures): autologous chondrogenesis induced by collagen membrane that is autologous matrix-induced chondrogenesis (AMIC).

Debridement

Debridement of a cartilage lesion is a simple resection of affected and unstable parts within the cartilage itself or up to the subchondral bone. It is the simplest and still the most frequently used technique. K.J. Hancock et al. presented the data that out of 25,938 surgeries due to cartilage lesion 80.23% debridement was performed in 80.23% of cases, the technique of microfractures creation – in 21.37%, and OATS – only in 2.1%, although in a number of cases, various techniques were combined [5]. S.R. Montgomery et al. analyzed the data of one of the largest databases of orthopedic surgery in the USA (Pearl Diver Patient Record Database) for a 6-year period (2004 to 2009). They found that various types of surgery were used in 163,448 of the patients with knee LCL, although about 98% of them were debridement and microfractures creation [4]. The positive clinical results of debridement deteriorated over time. Destructive changes rapidly progressed in the cartilage tissue leading to degenerative-dystrophic process in the joint in the mid- and long-term follow-up [9, 10]. Thus, S. Abram et al. found, based on the analysis of the statistics of all hospitalization in England from 2007 to 2017, that 8 years after knee debridement, 17.6% of the patients underwent subsequent arthroplasty [15].

Stimulation of chondrogenesis

The methods of chondrogenesis stimulation by manipulation on the cartilage lesion and subchondral bone widely spread due to the satisfactory short-term results, the relative simplicity and low cost of the surgery [14, 16]. The accumulated experience of their clinical application revealed a number of significant disadvantages: the resulting fibrous cartilage had worse mechanical properties in comparison with hyaline. It is not stable to tangential forces and, under physiological stress, degenerates over time [17], it is problematic to achieve congruence of the articular surfaces. In about 50% of the cases, the hypertrophied growth of newly formed tissue occurred resulting in reoperations [18]. According to a number of authors, unsatisfactory mid-term functional results, observed in 5 years after microfracturing, were an indication for reoperation in 26 to 40% of the patients, in which total knee arthroplasty was performed in 56% of cases [19, 20, 21, 22].

Comparison of the clinical efficacy of chondrogenesis stimulation methods demonstrated the advantage of the results of the microfracture technique (a total of 90.0% of excellent and good results in 3 years and 69.3% in 7 years after the surgery) compared to tunnelization (82.4% in 3 years and 65,0% in 7 years) and abrasive chondroplasty (72.4% in 3 years and 55.6% in 7 years) [23]. The regeneration slowdown and rapid destruction of the newly formed tissue were observed in the patients over 35 years old, with a high level of physical activity, overweight, lesions to the intra-articular structures, axial deformities of the limb [14, 24].

The further striving of surgeons to improve the LCL treatment long-term results led to the development and clinical application of tissues implants contained chondrocytes or cells capable of chondrogenesis [12, 25, 26, 27, 28, 29].

Transplantation of bone-cartilage allo- and autografts

The first technology that made it possible to replace articular surface lesions with hyaline cartilage, was mosaic plasty (OATS). Transplantation of allogeneic bone-cartilage grafts popularized by A.P. Newman and R.F. Convery et al. allowed achieving positive out-

comes in 72.0 to 77.5% of the patients with follow-up periods from 2 to 7 years after the surgery. The best results were achieved after transplantation of freshly frozen tissues [26, 27]. In a systematic review of 19 studies, including 1036 patients, F. Familiari et al. demonstrated that the effectiveness of this technique in the longer term remained very high: 86.7% in 5 years; 78.7% in 10 years; 72.8% in 15 years and 67.5% in 20 years. The number of unsatisfactory outcomes over such a long follow-up was 18.2%, and reoperations were required in 30.2% of the patients [30]. The undoubted advantage of this approach is the ability to restore defects of any extent because the donor material is unlimited.

Mosaic autograft transplantation (OATS) developed and introduced into clinical practice by L. Hangody, V. Bobic, and Y. Matsusue et al., presents an opportunity to use cylindrical grafts of various diameters and fill 80 to 100% of femoral condyles deep lesions up to 4 to 6 cm^2 with a material contained 80–90% of hyaline cartilage and 10–20% of fibrous tissue [28, 29, 31, 32, 33]. The typical zones of autografts collection are the peripheral low-load sections of the patellar groove and intercondylar fossa of the femur. If the lesion area is more than 6 cm^2, then additional autografts can be taken from the contralateral knee.

Positive results of OATS in 80–90% of the patients persist for 5 to 10 years after the surgery [31, 34]. The long-term results of OATS have been studied in 3 randomized clinical trials. R. Gudas et al. showed that, on average, in 10.4 years (9 to 11 years), this technique both clinically and radiologically was superior to microfracturing. 75% of professional athletes were able to maintain the same level of activity as it was before injury in contrast to 37% after microfracturing. The OATS failure rate was 2.7 times lower: 14% compared to 38% [20]. On the contrary, S. Ulstein et al. found no differences in the scoring of the knee function, muscle strength, and X-ray picture in 9.8 years after applying the both techniques. However, revisions after microfracturing were performed more often (54%) than after OATS (36%) [35]. In a comparative assessment of the outcomes of OATS and microfracturing in at least 15 years (15 to 17 years), E. Solheim et al. revealed that the first method was characterized by significantly better clinical results with a greater proportion of good and excellent outcomes, the score for knee function was significantly higher, the need for arthroplasty occurs less frequently: 5 vs 15% [36].

Thus, the long-term results of the high level of evidence studies indicated that OATS was a reliable and clinically more effective method of repairing knee cartilaginous and osteochondral lesions compared with subchondral bone microfracturing.

Autochondrocyte culture transplantation

In the first decade of the XXI century, the considerable interest of researchers was attracted by the possibility of using autologous cell cultures (chondrocytes, MMSC) for the LCL treatment [28, 29]. The first attempts to use the intra-articular injection of chondrocytes, isolated by proteolytic enzymes from the cartilage of low weight-bearing parts of the joint and cultured in vitro for the purpose of their expansion and adhesion into the lesion area, demonstrated promising short-term clinical, X-ray, MRI and histological results. The problem was to maintain the phenotype of chondrocytes in monolayer culture. There also was a risk of inhomogeneous distribution of cell suspension in the lesion zone [28, 37]. To increase the autochondrocytes concentration and to keep them in the cartilage lesion area, a ACI technique was developed for implanting cells under the periosteal flap. The analysis of long-term surgical results was controversial: with an average follow-up period (5.0 to 7.5 years), reoperations were observed in 8.0 to 8.18% of the patients [38, 39]. An increase in the follow-up to 10 years revealed the need for revision in 25% of the cases. Knee arthroplasty was performed in 36% of the patients [39]. The opposite results were presented by J. Carey et

al. 13% of the patients received ACI for knee osteochondritis dissecans needed additional surgery in the first 10 years after the primary surgery, 15% – within 15 years and 18% – up to 20 years. Knee arthroplasty was performed only in two cases out of 55 (3.7%) [40]. E. Kon et al. emphasized the following limitations of the technique: it was technically difficult to harvest the periosteum and create an airtight cavity in the area of cartilage lesion; there were frequent cases of hypertrophic proliferation of the new tissue, as well as arthrofibrosis required mobilization interventions [41].

The elimination of these disadvantages was facilitated by the method of implantation of autochondrocytes under collagen membranes/matrices (MACI), demonstrated the potential of chondroinduction and chondroconduction in vivo, the possibility of complete purification from non-collagen proteins, a low immunogenic effect and high biological compatibility [12]. Several types of membranes are currently available: Chondro-Gide (Geistlich Biomaterials), ChondroCelect (TiGenix), Carticel (Genzyme Biosurgery), Novocart Basic (Aesculap). Collagen membranes have a positive effect on the differentiation of MMSC culture toward the chondrogenic direction. As a result, the extracellular matrix characteristic of hyaline cartilage is formed and the synthesis of key proteins, such as type II collagen, aggrecan, local release of the bioactive factor TGF-β1 increases. These favor the cartilage tissue regeneration [42, 43, 44]. The disadvantages of the MACI technique are considered to be the technical complexity and the high cost of the surgery, a long rehabilitation period, problems of cultivation and maintenance of the phenotype, uniform distribution and retention of implanted cells in the lesion area [45, 46].

A number of systematic reviews concluded that the use of a collagen matrix made it possible to significantly reduce the level of revisions compared with a periosteal flap: according to A. Pareek et al. – from 52.6 to 15.1%, and J.D. Harris et al. 5.3 times – from 8 to 1.5% [47, 48]. However, there are no randomized clinical trials comparing 10-year or longer-term results for the both methods.

The accumulated experience of the clinical application of MACI was reflected in a large number of works published in the last 5 years [46, 49, 50, 51, 52]. The results, according to multicenter studies, were good and excellent in 84% in 4 years follow-up after the surgery [38], with an extension of follow-up to 10 years, the results remained the same in 80 to 90% of the patients [46, 47]. P. Kreuz et al. in a prospective study of 21 patients with full-thickness cartilage lesions assessed the long-term results of the MACI technique. The patients had significantly higher indicators than before surgery in 12 years after the surgery according to the subjective scales of IKDC, KOOS, Lysholm, Noyes. The complete or almost complete replacement of a cartilage lesion was achieved in 10 cases out of 14 according to MRI data [52]. Nevertheless, the failure rate in MACI could reach 14.9 to 19.0%. Most of them developed within the first 5 years, requiring total or unicompartmental knee arthroplasty [50, 51].

Multipotent mesenchymal stem cell transplantation

The wish to overcome the problems and reduce the material costs associated with the cultivation of autochondrocytes, to avoid additional trauma to the cartilage during the cells collection, the experimentally and clinically proven ability of MMSC to differentiate into chondrocytes, stimulated by collagen membranes, promoted the use of stem cells for LCL treatment by their intraarticular injection [53, 54] or implantation under the collagen membrane [14, 55]. Immediate and mid-term outcomes of such operations demonstrated encouraging clinical, X-ray, MRI and histological results [55, 56]. A. Teo et al., based on a comparative analysis of 62 patients treatment results after MMSC transplantation and the ACI technique with a minimum follow-up of 10 years, concluded that there were no significant subjective clinical differences between the

groups. These both techniques were equally effective in the long term, with reoperations after ACI required in 6 cases, while using MMSC – in 5, including one arthroplasty [57].

Combination of the techniques: microfractures and collagen membrane

Similar arguments served as a theoretical justification and wide clinical application of the combined technique (membrane+microfractures/AMIC), which provides the formation of a "super clot" from the blood, entering the area of cartilage lesion after subchondral bone microfractures, stable fixation by the collagen membrane and MMSC differentiation into chondrocytes, stimulated by the membrane [58, 59, 60].

A significant number of researches and publications are devoted to the study of the AMIC effectiveness [58, 59, 60, 61, 63, 64, 65, 66, 67]. The clinical results assessed by functional scales were found to be comparable to the clinical outcomes of ACI in 1 and 2 years after the surgery [58, 60, 62, 63, 66]. The high functional scales indicators, the degree of patient satisfaction (subjective assessment), and restoration of the homogeneous morphology of the cartilaginous lesion from moderate to complete according to MRI data remained in 5 years [61, 67].

S. Bark et al., analyzing 28 studies, including 3122 patients, devoted to comparing the outcomes of the microfracture and the AMIC technique, concluded that the clinical and MRI results of the AMIC are superior to those of microfracturing in the mid-term perspective [68]. M. Volz et al. compared the results of microfracturing and AMIC achieved in a randomized controlled trial. Improvement of clinical results by the knee function scales and MRI indicators was observed in both subgroups in 2 years after the surgery. However, 5 years later, a stable positive functional result was maintained and the filling of the lesion, according to MRI data, was more complete, while these parameters significantly worsened in the microfracturing subgroup [69]. Although a few randomized clinical trials indicated that the beneficial effect of AMIC could last up to 9 years [70]. Nevertheless, the authors of a recent systematic review of 28 studies of this technique, stated that there were only few well-conducted studies evaluated AMIC in comparison with more thoroughly studied techniques for creating microfractures, OATS and ACI. This made it difficult to determine clear clinical indications for using of the AMIC [71].

Currently, a promising alternative to the AMIC is the use of various types of special hydrogels, which are porous synthetic or biological polymers with a cross-structured composition that can be used as a matrix instead of a collagen membrane [72]. Evaluation of the nearest results showed that in terms of up to 2 years, the use of hydrogels led to filling of the cartilage lesion by more than 90%, which, in subjective assessment, exceeded the results of microfracturing [73, 74]. However, the longer-term results are needed to compare the clinical efficacy of hydrogels with other treatments of LCL.

How often are various cartilage restoration techniques used in real clinical practice?

It is interesting to compare the popularity of so many techniques used to treat LCL in everyday clinical practice.

R.M. Frank et al., based on the analysis of the Large US Commercial Database, contained information on 47,207 LCL surgeries, published the following data on the frequentness of various methods: microfracturing were used in 43,576 patients, OATS – in 1383, bone-cartilage alloplasty – in 714, and ACI – in 640 patients. In 65% of the cases, the simultaneous meniscectomy was performed. Two years later, 29.69% of the patients underwent reoperations after ACI, 14.65% – after microfracturing, 12.22% – after osteochondral alloplasty, and 8.82% – after OATS [75]. It remains unclear why OATS, which is the most effective, technically not complex and does not require large material expendi-

tures, is used in clinical practice quite infrequently both in our country and abroad?

Also, the figures on the rate of revisions differ significantly. According to the German Cartilage Registry for 2013–2017, only 3.3% of the patients, out of 2659 cases of knee LCL surgery, required reoperation in 12 months. There were no statistically significant differences in the number of revisions depending both on the surgical technique used and on the location of the lesion [76].

The similar data were presented by C. Riboh et al. They compared the effectiveness of the microfracture technique, OATS, 1st generation ACI, and MACI in 855 operated patients. Within 2 years after the surgery, there was no significant difference among the above groups in the number of revisions and the achieved functional results according to the functional scales. However, 5 years later, the level of revisions became higher after microfracturing. 10 years later, the "rating of effectiveness" of the techniques was presented as follows: MACI – ACI – OATS – microfracturing [77]. B.M. Devitt et al. published their own "rating of effectiveness" based on the results of a 10 years follow-up: MACI – OATS – microfracturing [78]. In contrast, in a multicenter, randomized clinical trial, 15 years after the surgery, the authors were unable to identify any significant differences in the treatment outcomes between the groups of patients received microfracturing and ACI [79]. The latest systematic review, published in 2020 by R. Zamborsky et al., showed that in the long term (10 or more years) microfracturing was significantly inferior in the effectiveness and the number of complications to other methods of LCL treatment. In addition, the authors found only few qualitative enough studies compared the results of ACI, MACI and AMIC. They concluded that to assess the long-term effectiveness of these methods it was necessary to conduct the appropriate randomized clinical trials [80].

The size of the lesion is an important factor in comparative assessment of various LCL treatment methods effectiveness. R. Ossendorf et al. conducted a comparative assessment of 10-year results of 44 LCL patients treatment using microfracturing and ACI. According to the subjective scales IKDC, KOOS, VAS, as well as the MRI indicators, no significant differences were found between the groups. The study indicated that the area of the lesion was significantly larger in the ACI group (4.34 cm2 vs 2.37 cm2), which had a significant impact on the final results [81].

G. Bentley et al., comparing the results of OATS and MACI in 100 patients in 10 years after the surgery, came to the following conclusions: during the 1st two years, the results of OATS were more than satisfactory, but then there was a sharp deterioration of the functional scales scores, while the level of achieved results in the MACI group did not change during 10 year follow-up. Functional outcomes and survival rate were also significantly better in the MACI group. The mean period between primary surgery and revision was 5.1 years for the patients in the MACI group and 4.3 years for the patients in the OATS group. The 10-year surgery outcome after mosaic chondroplasty in 55% of the patients was assessed as unsuccessful, compared with 17% in the MACI group [82].

V. Fossum et al., conducting a prospective randomized clinical study of AMIC effectiveness in comparison with MACI, did not find any significant differences between the two groups of the patients in terms of pain syndrome severity and knee functional state in 2 years follow-up. Although after AMIC, two patients required total knee arthroplasty [83].

It is of interest to study the minimally significant differences in assessing the long-term results of using various methods of surgical repair of cartilage lesions, assessed by the patients themselves. According to the results of 89 studies, including 3894 cases, with various scoring systems of knee functional assessment, only OATS and ACI demonstrated high effectiveness over a period of more than 10 years [84]. The long-term results of

randomized clinical trials of the effectiveness of various methods of knee LCL treatment are presented in the Table.

The economic effectiveness analysis of various LCL treatment methods is also important. Thus, J. Schrock et al. estimated the cost of microfracturing at $3989, OATS – at $6110, and ACI – at $10,195. The latter method was also characterized by the highest cost of revisions (on average $730) due to regenerated tissue hypertrophy or contracture development. The cost of one point of functional improvement was $200 for microfracturing, $313 for OATS, and $536 for ACI [85].

Table

The results of randomized clinical trials evaluated the long-term effectiveness of various methods of LCL treatment

Author, (year)	The size of the lesion, cm^2	Method	Number of patients	Follow-up, years	Relapse/ unsatisfactory outcome	p
Gudas R.G. (2012) [20]	2.8 (1–4)	Microfracturing OATS	29 28	10.4	38% (11 из 29) 14% (4 из 28)	<0.05
Gudas R.G. (2012) [20]	3.5 (2–5)	Microfracturing OATS	20 20	15	80% (16 из 20) 40% (8 из 20)	<0.05
Knutsen G. (2016) [79]	2–10	Microfracturing ACI	40 40	15	32.5% (13 из 40) 42.5% (17 из 40)	0.356
Bentley G. (2012) [76]	4.0 (1–20) 4.4 (1–10)	OATS ACI	42 58	10–12	55% (23 из 42) 17% (10 из 58)	<0.001
Volz M. (2017) [69]	3.6 (2–10)	Microfracturing AMIC	9 30	5	66% (6 из 9) 7% (2 из 30)	<0.01

Thus, despite the fact that during the past two decades, new methods of LCL surgical treatment using membranes and cell technologies (MMSC, ACI, MACI, AMIC) were introduced into clinical practice, they remain quite expensive, and their long-term benefits are insufficiently studied. Technically simple and cheap methods of stimulating chondrogenesis by forming a blood clot are inferior in their clinical effectiveness and reliability to all other methods and therefore should be used extremely limitedly, only in minimal defects. OATS is a simple, easily reproducible and time-tested option for the restoration of chondral and osteochondral lesions, therefore, in our opinion, it can be recommended as the method of choice. The combination of membranes with various cellular products or microfractures is indicated in case of extensive LCL or when OATS is impossible.

Competing interest: The authors declare no conflict of interest.

Funding: The state budget.

Authors' contributions

T.A. Kulyaba – review idea and concept, analysis and interpretation of publications search results on the topic, final editing.

S.A. Bantser – publications search on the topic and their analysis, text preparation.

P.A. Trachuk – publications search on the topic, their analysis and description.

N.N. Kornilov – review idea and concept, analysis and interpretation of publications search results on the topic, final editing.

All authors made a significant contribution to the research and preparation of the article and read and approved the final version before its publication. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Aleman O. Chondromalacia post-traumatica patellae. Acta Chir Scand. 1928;63:194.

2. Hjelle K., Solheim E., Strand T., Muri R., Brittberg M. Articular cartilage defects in 1,000 knee arthroscopies. Arthroscopy. 2002;18(7):730-734. doi: 10.1053/jars.2002.32839.
3. Gaissmaier C., Fritz J., Schewe B., Weise K., Mollenhauer J., Aicher W. Cartilage defects: epidemiology and natural history. Osteosynthesis and Trauma Care. 2006;14(3):188-194. doi: 10.1055/s-2006-942234.
4. Montgomery S.R., Foster B.D., Ngo S.S., Terrell R.D., Wang J.C., Petrigliano F.A., McAllister D.R. Trends in the surgical treatment of articular cartilage defects of the knee in the United States. Knee Surg Sports Traumatol Arthrosc. 2014;22(9):2070-2075. doi: 10.1007/s00167-013-2614-9.
5. Hancock K.J., Westermann R.R., Shamrock A.G., Duchman K.R., Wolf B.R., Amendola A. Trends in knee articular cartilage treatments: an American board of orthopaedic surgery database study. J Knee Surg. 2019;32(1):85-90. doi: 10.1055/s-0038-1635110.
6. Aroen A., Loken S., Heir S., Alvik E., Ekeland A., Granlund O.G., Engebretsen L. Articular cartilage lesions in 993 consecutive knee arthroscopies. Am J Sports Med. 2004;32(1):211-215. doi: 10/1177/0363546403259345.
7. Farr J., Cole B., Dhawan A., Kercher J., Sherman S. Clinical cartilage restoration: evolution and overview. Clin Orthop Relat Res. 2011;469(10):2696-2705. doi: 10.1007/s11999-010-1764-z.
8. Shirazi R., Shirazi-Adl A. Computational biomechanics of articular cartilage of human knee joint: effect of osteochondral defects. J Biomech. 2009;42(15):2458-2465. doi: 10.1016/j.jbiomech.2009.07.022.
9. Hafezi-Nejad N., Zikria B., Eng J., Carrino J.A., Demehri S. Predictive value of semi-quantitative MRI-based scoring systems for future knee replacement: data from the osteoarthritis initiative. Skeletal Radiol. 2015;44(11):1655-1662. doi: 10.1007/s00256-015-2217-2.
10. Jungmann P.M., Gersing A.S., Baumann F., Holwein C., Braun S., Neumann J., et al. Cartilage repair surgery prevents progression of knee degeneration. Knee Surg Sports Traumatol Arthrosc. 2019;27(9):3001-3013. doi: 10.1007/s00167-018-5321-8.
11. Kon E., Filardo G., Di Matteo B., Perdisa F., Marcacci M. Matrix assisted autologous chondrocyte transplantation for cartilage treatment: A systematic review. Bone Joint Res. 2013;2(2):18-25. doi: 10.1302/2046-3758.22.2000092.
12. Filardo G., Kon E., Roffi A., Di Martino A., Marcacci M. Scaffold-based repair for cartilage healing: a systematic review and technical note. Arthroscopy. 2013;29(1):174-186. doi: 10.1016/j.arthro.2012.05.891.
13. Mironov S.P., Omelyanenko N.P., Kon E., Orleckij A.K., Karpov I.N., Kupryakov A.P. [Cartilage defects classification and treatment methods]. Vestnik travmatologii i ortopedii im N.N. Priorova [N.N. Priorov Journal of Traumatology and Orthopedics]. 2008;(3): 81-85. (In Russian).
14. Richter D.L., Schenck R.C. Jr., Wascher D.C., Treme G. Knee Articular Cartilage Repair and Restoration Techniques: A Review of the Literature. Sports Health. 2016;8(2):153-160. doi: 10.1177/1941738115611350
15. Abram S.G.F., Palmer A.J.R., Judge A., Beard D.J., PriceA.J.Ratesofkneearthroplastyinpatientswithahistory of arthroscopic chondroplasty: results from a retrospective cohort study utilising the National Hospital Episode Statistics for England. BMJ Open. 2020;10(4):e030609. doi: 10.1136/bmjopen-2019-030609.
16. Jacobi M., Villa V., Magnussen R.A., Neyret P. MACI — a new era? Sports Med Arthrosc Rehabil Ther Technol. 2011;3(1):10. doi: 10.1186/1758-2555-3-10.
17. Dorotka R., Windberger U., Macfelda K., Bindreiter U., Toma C., Nehrer S. Repair of articular cartilage defects treated by microfracture and a three-dimensional collagen matrix. Biomaterials. 2005;26(17):3617-3629.
18. Gooding C.R., Bartlett W., Bentley G., Skinner J.A., Carrington R., Flanagan A. A prospective, randomised study comparing two techniques of autologous chondrocyte implantation for osteochondral defects in the knee: Periosteum covered versus type I/III collagen covered. Knee. 2006;13(3):203-210. doi: 10.1016/j.knee.2006.02.011.
19. Pestka J.M., Bode G., Salzmann G., Sudkamp N.P., Niemeyer P. Clinical outcome of autologous chondrocyte implantation for failed microfracture treatment of full-thickness cartilage defects of the knee joint. Am J Sports Med. 2012;40(2):325-331. doi: 10.1177/0363546511425651.
20. Gudas R., Gudaite A., Pocius A., Gudiene A., Cekanauskas E., Monastyreckiene E., Basevicius A. Ten-year follow-up of a prospective, randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint of athletes. Am J Sports Med. 2012;40(11):2499-2508. doi: 10.1177/0363546512458763.
21. Salzmann G.M., Sah B., Sudkamp N.P., Niemeyer P. Reoperative characteristics after microfracture of knee cartilage lesions in 454 patients. Knee Surg Sports Traumatol Arthrosc. 2013;21(2):365-371. doi: 10.1007/s00167-012-1973-y.
22. Layton A., Arnold R.J., Graham J., Frasco M.A., Cote E., Lynch N.M. Long-term failure rates associated with knee microfracture surgery. Value in health. 2015;18(3):A156. doi: 10.1016/j.jval.2015.03.905.
23. Ehjsmont O.L., Borisov A.V., Malyuk B.V., Bukach D.V. [Arthroscopic diagnosis and treatment of local injuries of the knee cartilage]. Ortopediya travmatologiya i protezirovanie [Orthopedics, Traumatology and Prosthetics]. 2007;(3):111-116. (In Russian).
24. Kotelnikov G.P., Volova L.T., Lartsev Y.V., Dolgushkin D.A., Terteryan M.A. [The new plastic method of articular hyaline cartilage defects with combined cellular-tissue graft]. Travmatologiya i ortopediya Rossii [Traumatology and Orthopedics of Russia]. 2010;(1):150-155. (In Russian). doi: 10.21823/2311-2905-2010-0-1-150-155.
25. Hangody L., Vasarhelyi G., Hangody L.R., Sukosd Z., Tibay G., Bartha L., Bodo G. Autologous osteochondral grafting-technique and long-term results. Injury. 2008;39(1):32-39. doi: 10.1016/j.injury.2008.01.041.
26. Newman A.P. Articular cartilage repair. Am J Sports Med. 1998;26(2):309-324.

27. Convery R.F., Akeson W.N., Meyers M.H. The operative technique of fresh osteochondral allografting of the knee. Operative Techniq Orthop. 1997;7(4):340-344.
28. Brittberg M. Autologous chondrocyte implantation-technique and long-term follow-up. Injury. 2008;39(1):40-49. doi: 10.1016/j.injury.2008.01.040.
29. Minas T., Gomoll A.H., Solhpour S., Rosenberger R., Probst C., Bryant T. Autologous chondrocyte implantation for joint preservation in patients with early osteoarthritis. Clin Orthop Relat Res. 2010;468(1):147-157. doi: 10.1007/s11999-009-0998-0.
30. Familiari F., Cinque M.E., Chahla J., Godin J.A., Olesen M.L., Moatshe G., LaPrade R.F. Clinical Outcomes and Failure Rates of Osteochondral Allograft Transplantation in the Knee: A Systematic Review. Am J Sports Med. 2018;46(14):3541-3549. doi: 10.1177/0363546517732531.
31. Hangody L., Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. J Bone Joint Surg Am. 2003;85-A(2):25-32.
32. Bobic V. Arthroscopic osteochondral autograft transplantation in anterior cruciate ligament reconstruction: a preliminary clinical study. Knee Surg Traumatol Arthrosc. 1996;(3):262-264. doi: 10.1007/bf01466630.
33. Matsusue Y., Kotake T., Nakagawa Y., Nakamura T. Arthroscopic osteochondral autograft transplantation for chondral lesion of the tibial plateau of the knee. Arthroscopy. 2001;17(6):653-659. doi: 10/1053/jars.2001.22400.
34. Kulyaba T.A., Kornilov N.N., Selin A.V., Pechinskij A.I. [Long-term results of mosaic osteochondral autoplasty in the treatment of diseases and injuries of the knee joint]. Travmatologiya i ortopediya Rossii [Traumatology and Orthopedics of Russia]. 2007;(3):24. (In Russian).
35. Ulstein S., Årøen A., Røtterud J.H., Løken S., Engebretsen L., Heir S. Microfracture technique versus osteochondral autologous transplantation mosaicplasty in patients with articular chondral lesions of the knee: a prospective randomized trial with long-term follow-up. Knee Surg Sports Traumatol Arthrosc. 2014;22(6):1207-1215. doi: 10.1007/s00167-014-2843-6.
36. Solheim E., Hegna J., Strand T., Harlem T., Inderhaug E. Randomized Study of Long-term (15-17 Years) Outcome After Microfracture Versus Mosaicplasty in Knee Articular Cartilage Defects. Am J Sports Med. 2018;46(4):826-831. doi: 10.1177/0363546517745281.
37. Koulalis D., Schultz W., Heyden M. Autologous chondrocyte transplantation for osteochondritis dissecans of the talus. Clin Orthop Relat Res. 2002;(395):186-192. doi: 10.1097/00003086-200202000-00021.
38. Gomoll A.H., Gillogly S.D., Cole B.J., Farr J., Arnold R., Hussey K., Minas T. Autologous chondrocyte implantation in the patella: a multicenter experience. Am J Sports Med. 2014;42(5):1074-1081. doi: 10.1177/0363546514523927.
39. Minas T., Von Keudell A., Bryant T., Gomoll A.H. The John Insall Award: A minimum 10-year outcome study of autologous chondrocyte implantation. Clin Orthop Relat Res. 2014;472(1):41-51. doi: 10.1007/s11999-013-3146-9.
40. Carey J.L., Shea K.G., Lindahl A., Vasiliadis H.S., Lindahl C., Peterson L. Autologous Chondrocyte Implantation as Treatment for Unsalvageable Osteochondritis Dissecans: 10- to 25-Year Follow-up. Am J Sports Med. 2020;48(5):1134-1140. doi: 10.1177/0363546520908588.
41. Kon E., Verdonk P., Condello V., Delcogliano M., Dhollander A., Filardo G., Pignotti E., Marcacci M. Matrix-assisted autologous chondrocyte transplantation for the repair of cartilage defects of the knee: systematic clinical data review and study quality analysis. Am J Sports Med. 2009;37(1):156-166. doi: 10.1177/0363546509351649.
42. Kramer J., Bohrnsen F., Lindner U., Behrens P., Schlenke P., Rohwedel J. In vivo matrix-guided human mesenchymal stem cells. Cell Mol Life Sci. 2006;63(5):616-626. doi: 10.1007/s00018-005-5527-z.
43. Martinez I., Elvenes J., Olsen R., Bertheussen K., Johansen O. Redifferentiation of in vitro expanded adult articular chondrocytes by combining the hanging-drop cultivation method with hypoxic environment. Cell Transplant. 2008;17(8):987-996. doi: 10.3727/096368908786576499.
44. Dickhut A., Dexheimer V., Martin K., Lauinger R., Heisel C., Richter W. Chondrogenesis of human mesenchymal stem cells by local transforming growth factor-beta delivery in a biphasic resorbable carrier. Tissue Eng Part A. 2010;16(2):453-464. doi: 10.1089/ten.TEA.2009.0168.
45. Hickery M.S., Bayliss M.T., Dudhia J., Lewthwaite J.C., Edwards J.C., Pitsillides A.A. Age-related changes in the response of human articular cartilage to IL-1alpha and transforming growth factor-beta (TGF-beta): chondrocytes exhibit a diminished sensitivity to TGF-beta. J Biol Chem. 2003;278(52):53063-53071. doi: 10.1074/jbc.M209632200.
46. Bentley G., Bhamra J.S., Gikas P.D., Skinner J.A., Carrington R., Briggs T.W. Repair of osteochondral defects in joints-how to achieve success. Injury. 2013;44(1):3-10. doi: 10.1016/S0020-1383(13)70003-2.
47. Pareek A., Carey J.L., Reardon P.J., Peterson L., Stuart M.J., Krych A.J. Long-term outcomes after autologous chondrocyte implantation: a systematic review at mean follow-up of 11.4 Years. Cartilage. 2016;7(4):298-308. doi: 10.1177/1947603516630786.
48. Harris J.D., Siston R.A., Brophy R.H., Lattermann C., Carey J.L., Flanigan D.C. Failures, re-operations, and complications after autologous chondrocyte implantation-a systematic review. Osteoarthritis Cartilage. 2011;19(7):779-791. doi: 10.1016/j.joca.2011.02.010.
49. Kon E., Filardo G., Di Matteo B., Perdisa F., Marcacci M. Matrix assisted autologous chondrocyte transplantation for cartilage treatment: A systematic review. Bone Joint Res. 2013;2(2):18-25. doi: 10.1302/2046-3758.22.2000092.
50. Andriolo L., Merli G., Filardo G., Marcacci M., Kon E. Failure of autologous chondrocyte implantation. Sports Med Arthrosc Rev. 2017;25(1):10-18. doi: 10.1097/JSA.0000000000000137.
51. de Windt T.S., Vonk L.A., Brittberg M., Saris D.B. Treatment and prevention of (early) osteoarthritis using articular cartilage repair-fact or fiction? A systematic review. Cartilage. 2013;4(3):5-12. doi: 10.1177/1947603513486560.

52. Kreuz P.C., Kalkreuth R.H., Niemeyer P., Uhl M., Erggelet C. Long-Term Clinical and MRI Results of Matrix-Assisted Autologous Chondrocyte Implantation for Articular Cartilage Defects of the Knee. Cartilage. 2019;10(3):305-313. doi:10.1177/1947603518756463.
53. Saw K.-Y., Loke S.-C., Tay Y.-G. A novel approach to neochondrogenesis indused by peripheral blood stem cells and hyaluronic acid. Presented at the British Orthopaedic Assotiation annual congress. BJP. 2013;114(11): 1610-1618. doi: 10.1152/japplphysiol.01132.2012.
54. Bozhokin M.S., Bozhkova S.A., Netylko G.I. [Possibilities of modern cellular technologies for the restoration of damaged articular cartilage (analytical review of the literature)]. Travmatologiya i ortopediya Rossii [Traumatology and Orthopedics of Russia]. 2016;22(3):122-134. (In Russian). doi: 10/21823/2311-2905-2016-22-3-122-134.
55. Wakitani S., Imoto K., Yamamoto T., Saito M., Murata N., Yoneda M. Human autologous culture expanded bone marrow mesenchymal cell transplantation for repair of cartilage defects in osteoarthritic knees. Osteoarthritis Cartilage. 2002;10(3):199-206. doi: 10.1053/joca.2001.0504.
56. Bryanskaya A.I., Kulyaba T.A., Kornilov N.N., Rumakin V.P., Gornostaev V.S. [Arthroplasty using autologous multipotent mesenchymal cells and Chondro-gide collagen membrane]. Vestnik travmatologii i ortopedii im N.N. Priorova [N.N. Priorov Journal of Traumatology and Orthopedics]. 2014;(1):62-66. (In Russian).
57. Teo A.Q.A., Wong K.L., Shen L., Lim J.Y., Toh W.S., Lee E.H., Hui J.H.P. Equivalent 10-Year Outcomes After Implantation of Autologous Bone Marrow-Derived Mesenchymal Stem Cells Versus Autologous Chondrocyte Implantation for Chondral Defects of the Knee. Am J Sports Med. 2019;47(12):2881-2887. doi: 10.1177/0363546519867933.
58. Lee Y.H., Suzer F., Thermann H. Autologous Matrix-induced chondrogenesis in the knee: a review. Cartilage. 2014;5(3):145-153. doi: 10.1177/1947603514529445.
59. Gille J., Behrens P., Volpi P., de Girolamo L., Reiss E., Zoch W., Anders S. Outcome of Autologous Matrix Induced Chondrogenesis (AMIC) in cartilage knee surgery: data of the AMIC Registry. Arch Orthop Trauma Surg. 2013;133(1):87-93. doi: 10.1007/s00402-012-1621-5.
60. Schiavone Panni A., Cerciello S., Vasso M. The manangement of knee cartilage defects with modified amic technique: preliminary results. Int J Immunopathol Pharmacol. 2011;24(1 Suppl 2):149-152. doi: 10.1177/03946320110241s228.
61. Gille J., Schuseil E., Wimmer J., Gellissen J., Schulz A.P., Behrens P. Mid-term results of Autologous Matrix-Induced Chondrogenesis for treatment of focal cartilage defects in the knee. Knee Surg Sports Traumatol Arthrosc. 2010;18(11):1456-1464. doi: 10.1007/s00167-010-1042-3.
62. Oheim R., Behrens P., Volpi P., Girolamo L., Reiss Eric E., Zoch W. et al. Mid-term results of autologous matrix induced chondrogenesis (amic) in cartilage knee surgery. Br J Sports Med. 2013;47(10):e3. doi: 10.1136/bjsports-2013-092558.6.
63. Anders S., Volz M., Frick H., Gellissen J. A randomized, controlled trial comparing autologous matrix-induced chondrogenesis (AMIC®) to microfracture: analysis of 1- and 2-year follow-up data of 2 centers. Open Orthop J. 2013;(3)7:133-143. doi: 10.2174/1874325001307010133.
64. Bertho P., Pauvert A., Pouderoux T., Robert H.; Orthopaedics and Traumatology Society of Western France (SOO). Treatment of large deep osteochondritis lesions of the knee by autologous matrix-induced chondrogenesis (AMIC): Preliminary results in 13 patients. Orthop Traumatol Surg Res. 2018;104(5):695-700. doi: 10.1016/j.otsr.2018.05.008.
65. Schiavone Panni A., Del Regno C., Mazzitelli G., D'Apolito R., Corona K., Vasso M. Good clinical results with autologous matrix-induced chondrogenesis (Amic) technique in large knee chondral defects. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1130-1136. doi: 10.1007/s00167-017-4503-0.
66. Schagemann J., Behrens P., Paech A., Riepenhof H., Kienast B., Mittelstadt H., Gille J. Mid-term outcome of arthroscopic AMIC for the treatment of articular cartilage defects in the knee joint is equivalent to mini-open procedures. Arch Orthop Trauma Surg. 2018;138(6):819-825. doi: 10.1007/s00402-018-2887-z.
67. Hoburg A., Leitsch J.M., Diederichs G., Lehnigk R., Perka C., Becker R., Scheffler S. Treatment of osteochondral defects with a combination of bone grafting and AMIC technique. Arch Orthop Trauma Surg. 2018;138(8):1117-1126. doi: 10.1007/s00402-018-2944-7.
68. Bark S., Piontek T., Behrens P., Mkalaluh S., Varoga D., Gille J. Enhanced microfracture techniques in cartilage knee surgery: Fact or fiction? World J Orthop. 2014;5(4):444-449. doi: 10.5312/wjo.v5.i4.444.
69. Volz M., Schaumburger J., Frick H., Grifka J., Anders S. A randomized controlled trial demonstrating sustained benefit of Autologous Matrix-Induced Chondrogenesis over microfracture at five years. Int Orthop. 2017;41(4):797-804. doi: 10.1007/s00264-016-3391-0.
70. de Girolamo L., Schönhuber H., Viganò M., Bait C., Quaglia A., Thiebat G., Volpi P. Autologous Matrix-Induced Chondrogenesis (AMIC) and AMIC Enhanced by Autologous Concentrated Bone Marrow Aspirate (BMAC) Allow for Stable Clinical and Functional Improvements at up to 9 Years Follow-Up: Results from a Randomized Controlled Study. J Clin Med. 2019;8(3):392. doi: 10.3390/jcm8030392.
71. Gao L., Orth P., Cucchiarini M., Madry H. Autologous Matrix-Induced Chondrogenesis: A Systematic Review of the Clinical Evidence. Am J Sports Med. 2019;47(1):222-231. doi:10.1177/0363546517740575.
72. Amini A.A., Nair L.S. Injectable hydrogels for bone and cartilage repair. Biomed Mater. 2012;7(2):024105. doi: 10.1088/1748-6041/7/2/024105.
73. Pipino G., Risitano S., Alviano F., Wu E.J., Bonsi L., Vaccarisi D.C., Indelli P.F. Microfractures and hydrogel scaffolds in the treatment of osteochondral knee defects: A clinical and histological evaluation. J Clin Orthop Trauma. 2019;10(1):67-75. doi: 10.1016/j.jcot.2018.03.001.
74. Wolf M.T., Zhang H., Sharma B., Marcus N.A., Pietzner U., Fickert S., Lueth A., Albers G.H.R., Elisseeff J.H. Two-Year Follow-Up and Remodeling Kinetics of ChonDux Hydrogel for Full-Thickness Cartilage Defect Repair in the Knee. Cartilage. 2018:1947603518800547. doi: 10.1177/1947603518800547. Epub ahead of print.
75. Frank R.M., McCormick F., Rosas S., Amoo-Achampong K., Erickson B., Bach B.R. Jr, Cole B.J. Reoperation rates after cartilage restoration procedures in the knee: analysis of a large US commercial database. Am

J Orthop (Belle Mead NJ). 2018;47(6). doi: 10.12788/ajo.2018.0040.
76. Pestka J.M., Luu N.H., Sudkamp N.P., Angele P., Spahn G., Zinser W., Niemeyer P. Revision surgery after cartilage repair: data from the German cartilage registry (KnorpelRegister DGOU). Orthop J Sports Med. 2018;6(2):2325967117752623. doi: 10.1177/2325967117752623.
77. Riboh J.C., Cvetanovich G.L., Cole B.J., Yanke A.B. Comparative efficacy of cartilage repair procedures in the knee: a network meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2017;25(12):3786-3799. doi: 10.1007/s00167-016-4300-1.
78. Devitt B.M., Bell S.W., Webster K.E., Feller J.A., Whitehead T.S. Surgical treatments of cartilage defects of the knee: Systematic review of randomized controlled trials. Knee. 2017;24(3):508-517. doi: 10.1016/j.knee.2016.12.002.
79. Knutsen G., Drogset J.O., Engebretsen L., Grøntvedt T., Ludvigsen T.C., Løken S., Solheim E., Strand T., Johansen O. A Randomized Multicenter Trial Comparing Autologous Chondrocyte Implantation with Microfracture: Long-Term Follow-up at 14 to 15 Years. J Bone Joint Surg Am. 2016;98(16):1332-1339. doi: 10.2106/JBJS.15.01208.
80. Zamborsky R., Danisovic L. Surgical Techniques for Knee Cartilage Repair: An Updated Large-Scale Systematic Review and Network Meta-analysis of Randomized Controlled Trials. Arthroscopy. 2020;36(3):845-858. doi: 10.1016/j.arthro.2019.11.096.
81. Ossendorff R., Franke K., Erdle B., Uhl M., Südkamp N.P., Salzmann G.M. Clinical and radiographical ten years long-term outcome of microfracture vs. autologous chondrocyte implantation: a matched-pair analysis. Int Orthop. 2019;43(3):553-559. doi: 10.1007/s00264-018-4025-5.
82. Bentley G., Biant L.C., Vijayan S., Macmull S., Skinner J.A., Carrington R.W. Minimum ten-year results of a prospective randomised study of autologous chondrocyte implantation versus mosaicplasty for symptomatic articular cartilage lesions of the knee. J Bone Joint Surg Br. 2012;94(4):504-509. doi: 10.1302/0301-620X.94B4.27495.
83. Fossum V., Hansen A.K., Wilsgaard T., Knutsen G. Collagen-Covered Autologous Chondrocyte Implantation Versus Autologous Matrix-Induced Chondrogenesis: A Randomized Trial Comparing 2 Methods for Repair of Cartilage Defects of the Knee. Orthop J Sports Med. 2019;7(9):2325967119868212. doi: 10.1177/2325967119868212.
84. Jones K.J., Kelley B.V., Arshi A., McAllister D.R., Fabricant P.D. Comparative Effectiveness of Cartilage Repair With Respect to the Minimal Clinically Important Difference. Am J Sports Med. 2019;47(13):3284-3293.
85. Schrock J.B., Kraeutler M.J., Houck D.A., McQueen M.B., McCarty E.C. A Cost-Effectiveness Analysis of Surgical Treatment Modalities for Chondral Lesions of the Knee: Microfracture, Osteochondral Autograft Transplantation, and Autologous Chondrocyte Implantation. Orthop J Sports Med. 2017;5(5):2325967117704634. doi: 10.1177/2325967117704634.

AUTHORS' INFORMATION:

Taras A. Kulyaba — Dr. Sci. (Med.), Head of the Knee Pathology Department, Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation
ORCID: https://orcid.org/0000-0003-3175-4756

Sergei A. Bantser — Cand. Sci. (Med.), Lecturer, Chair of Traumatology and Orthopedics, Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation
ORCID: https://orcid.org/0000-0002-7291-7032

Pavel A. Trachuk – Doctor, Pavlov First Saint-Petersburg State Medical University, St. Petersburg, Russian Federation
ORCID: https://orcid.org/0000-0002-4442-5381

Tatyana N. Vorontsova — Dr. Sci. (Med.), Head of Organization and Methodological Department, Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation
ORCID: https://orcid.org/0000-0002-4594-6655

Nikolai N. Kornilov — Dr. Sci. (Med.), Professor, Chair of Traumatology and Orthopedics, Head of Knee Surgery Department, Vreden National Medical Research Center of Traumatology and Orthopedics; Assistant Professor, Department of Traumatology and Orthopedics, Mechnikov North-Western State Medical University, St. Petersburg, Russian Federation
ORCID: https://orcid.org/0000-0001-6905-7900