

Technical Note

Arthroscopic Minced Cartilage Implantation for Chondral Lesions at the Talus: A Technical Note

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Abstract: In the past few years, autologous chondrocyte implantation has been shown to be the most suitable cartilage reconstructive technique with the best tissue quality. Although this method is part of the standard surgical repertoire in the knee joint, it has so far not been an established method in the ankle because there are no prospective randomized controlled studies to prove a significant advantage over alternative methods of cartilage repair. The methods most frequently used in this context (e.g., marrow stimulation techniques) can, however, at most generate hyaline-like and thus biomechanically inferior regenerates. Minced cartilage implantation, on the other hand, is a relatively simple and cost-effective 1-step procedure with promising biological potential and—at least in the knee joint—satisfactory clinical results. We present an arthroscopic surgical technique by which the surgeon can apply autologous chondrocytes in a 1-step procedure (AutoCart; Arthrex, Munich, Germany) to treat articular cartilage defects in the ankle joint.

Osteochondral lesions of the talus can occur spontaneously, as a result of acute and chronic instability of the ankle, or accompanying an ankle fracture. The incidence is estimated at 38% to 71% in the fracture situation and at 6.5% in acute instability cases.¹⁻³ Even if a traumatic genesis is the leading etiologic factor, various disease-inducing influences have been described in the literature.^{4,5}

Dissections with an intact cartilage shoulder remaining in situ are primarily treated conservatively.⁶ When conservative management fails or when the lesion is

not originally thought to be amenable to operative management, surgical treatment is indicated.⁷

Symptomatic cartilage defects across the ankle joint are currently treated with different cartilage repair techniques.⁸ The body of evidence regarding ankle cartilage repair techniques is based on both low-level and low-quality evidence.⁹ At the moment, treatment of cartilage defects of the ankle is still controversial.

Generally, there is growing evidence that repair tissue quality is related to clinical outcomes.^{9,10} The highest-possible repair tissue quality is connected to cell-based cartilage repair techniques.¹¹⁻¹³ These include autologous chondrocyte implantation (ACI) and autologous particulate cartilage chips (minced cartilage implantation [MCI]).¹⁴ As part of the ACI in a 2-step procedure, culture-expanded autologous chondrocytes are seeded on a scaffold, which is then secured in the lesion.^{8,15} A significant disadvantage of this procedure is that 2 interventions are necessary. Furthermore, it is known to have high costs and limited availability.¹⁶ In contrast, MCI is a 1-step off-the-shelf procedure and must therefore be assessed as an attractive alternative to other cartilage repair techniques.¹⁶⁻¹⁸ MCI is indicated in the knee joint for all (contained, isolated, and unipolar) lesion sizes and can also be applied in osteochondral defects.¹⁹ To what extent this observation also applies to the ankle is unclear. Previous descriptions of the procedure have concentrated exclusively on fresh particulate juvenile allograft chondrocytes transplanted at the lesion site.^{7,20-23} The application as an autologous cartilage

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reconstructive procedure, however, has not yet been described. The aim of this Technical Note is to present autologous minced cartilage transplantation via an arthroscopic approach.

Surgical Technique

The technique can be applied arthroscopically to all symptomatic full-thickness cartilage defects of the ankle joint when the defect zone is accessible to the arthroscopic approach (Video 1). The treatment of a subchondral cyst area is not part of this Technical Note but can also be performed arthroscopically if necessary. In general, the technique can also be performed with an open approach.

The technique presented in this article for a typical lesion of the medial talar shoulder (Fig 1) can also be carried out in other talar regions or on the tibial plafond. Coexisting pathologies such as ligamentous instability and mechanical axis malalignment of the hindfoot are crucial to be identified and treated sufficiently. Such intervention can be performed simultaneously.

Perioperative antibiotic prophylaxis is recommended yet not without conflicting evidence. To avoid negative effects on the platelet-rich plasma (PRP), it is recommended to perform blood drawing (e.g., cubital veins) under sterile conditions before anesthesia is initiated; 10 to 15 mL of PRP is required.

The patient position is supine. Use of a tourniquet is recommended to implant the cartilage under bloodless circumstances. Standard diagnostic ankle arthroscopy (Fig 2 A and B) is performed to address any



Fig 1. Left side, preoperative magnetic resonance imaging showing full-thickness cartilage defect of medial talar shoulder in sagittal plane. The arrows point to the defect area.

concomitant intra-articular pathology. As soon as the defect is identified and the decision is made to perform treatment with minced cartilage via the AutoCart procedure (Arthrex, Munich, Germany), the defect must be prepared meticulously and suitable donor cartilage must be harvested. The use of degenerative cartilage or synovium for further transplantation is not recommended. Degenerative synovial and fibrous tissue parts are removed with a shaver device, thus determining the extent of the defect. The cartilage defect is debrided in a standardized fashion by using a small sharp spoon or ringed curette. After standard debridement of the lesion, the cartilage can subsequently be harvested at this location. The aim is to preserve and harvest vital cartilage areas for transplantation while creating vertical defect margins. The typical and recommended harvest site is the cartilage defect edge. Loose or unattached but visually vital cartilage parts can be included in the removal (Fig 2 C and D). The defect itself should be only minimally enlarged if not enough cartilage can be collected in the surrounding area. Aurich et al.⁵ described a superior redifferentiation of chondrocytes harvested from the edge of the defect compared with non-weight-bearing regions in the knee joint.

It is recommended to harvest cartilage with a 3.0-mm shaver device. A collecting device (e.g., Arthrex Graft-Net) is connected in advance to the shaver for harvesting. By use of this method, cartilage is harvested and then minced into small fragments (paste-like) and collected at once.^{24,25} Subsequently, the minced cartilage chips are mixed with 2 to 3 drops of PRP, resulting a pasty substance. An applicator (obturator) device is loaded with the mixture of chips and PRP. After loading, 3 mL of PRP is inserted into the Thrombinator system (Arthrex) and is gently mixed. After 10 to 15 minutes of incubation, autologous thrombin will be generated. After application of another 5 mL of PRP into the same device, the thrombin will be ready for application onto the defect bed. At the end of the procedure, arthroscopic water influx is discontinued and the joint is dried using swabs or similar devices (Fig 2E).

Any subchondral cancellous bone substitute that may be necessary is distributed in the defect bed and applied in a press-fit manner. The defect filling should be performed to the level of the adjacent subchondral bone. The cancellous bone can also be mixed with PRP if necessary.

The autologous chips are brought into the defective region by using the applicator device (Fig 2 F and G). The chip-PRP paste is distributed over the defect as a whole for complete coverage. It is not necessary to fill to the height of the surrounding cartilage edge; approximately 80% to 90% filling is sufficient. The consistency of the chip paste will provide initial stability. In the next step, the thrombin that has just been gathered from the

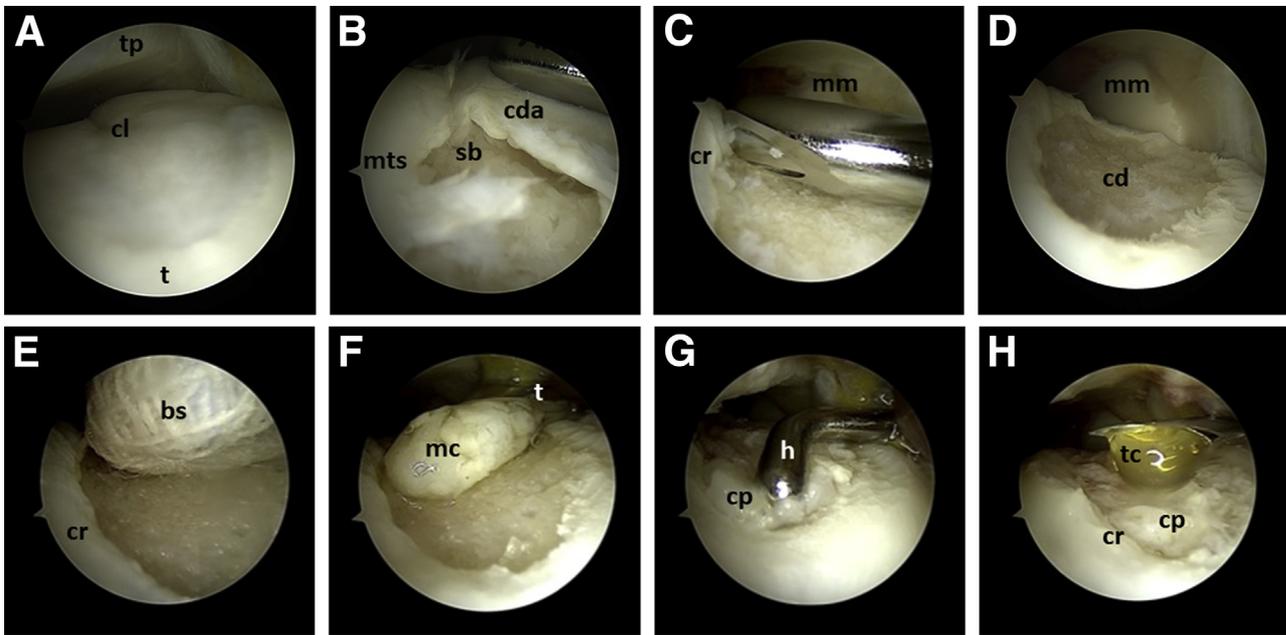


Fig 2. (A) Chondral damage to medial talar shoulder: arthroscopic view from anterolateral portal using 2.8-mm scope with patient in supine position. (cl, chondral lesion; t, talus; tp, tibial plateau.) (B) Instable chondral lamella. (cda, delaminated area; mts, medial talar shoulder; sb, subchondral bone.) (C) Harvesting of vital cartilage from detached cartilage and from defect edges using 3.0-mm Sabre shaver blade (Arthrex, Naples, FL). (cr, chondral rim; mm, medial malleolus.) (D) Creation of stable vertical wall in lesion area. (cd, cartilage defect; mm, medial malleolus.) (E) Subtle drainage and drying of defect bed. (bs, ball swab; cr, cartilage rim.) (F) Insertion of particulate cartilage through trocar. (mc, minced cartilage; t, trocar.) (G) Distribution of minced cartilage below level of surrounding cartilage. (cp, chondral particles; h, hook.) (H) Application of thrombin for adhesion of particles. (cp, chondral particles; cr, chondral rim; tc, thrombin clot.)

Thrombinator is applied drop by drop over the chip paste (Fig 2H). The thrombin will combine with the PRP within the chips and generate fibrin, which coagulates rapidly, thus fixing the chips within the cartilage defect. One has the option of additionally sealing the tissue with a final layer of fibrin that has been prepared in advance on a back table. This completes the procedure. An optional drain without suction can be applied. The ankle must be fixated in the neutral position in a brace. Initially, approximately 20 to 24 hours of bed rest is suggested. Thereafter, a standardized rehabilitation protocol is suggested as described elsewhere.²⁶

Discussion

Previously, it has been shown that the principle of minced cartilage functions very well regarding repairing chondral and osteochondral lesions.²⁷ So far, most reports have concentrated on the application thereof in the knee joint.

Several techniques have been published displaying success in the repair of joint surface lesions at the ankle. Mostly, drilling procedures, osteochondral transplantations, allogeneic tissue, or empty membranes have been used.⁵ Particularly at the ankle, however, chronic osteochondral lesions or freshly delaminated purely chondral lesions are frequent. Associated chondral material remains vital.²⁸ Such chondrocytes can be used for

location-specific application. This method offers an attractive solution whereby such tissue is not discarded but rather is processed intraoperatively and then directly reimplanted, providing many advantages at the same time. This is a 1-step procedure consisting purely of autologous tissue without creating substantial change during manipulation.

Autologous minced cartilage repair was first introduced in the early 1980s. The principle of minced cartilage techniques is to accomplish hyaline-like chondral repair through the use of “minced” pieces of autologous hyaline cartilage.²⁹ The cartilage fragments are a source of viable chondrocytes that migrate and produce a matrix and collagen.³⁰ The newly established chondrocyte population and cartilage tissue can fill defects and can integrate with existing native cartilage and/or subchondral bone at the treatment site.³¹ Lind and Larsen³² showed equality in cartilage repair capacity between a cell-based 1-step minced cartilage repair procedure and the standard ACI procedure in sheep.

The degree of fragmentation is very important. When cartilage chips are left too large, the surface is too small for chondrocytes to become active. Additionally, large pieces might not incorporate well into existing cartilage.¹⁶ Therefore, the use of a scalpel to yield particulate harvested cartilage is assumed to be unsuitable.²⁵ Morscellation of cartilage into approximately 1-mm³ pieces

Table 1. Pearls and Pitfalls of Minced Cartilage Implantation at Talus

Pearls	
	Pure autologous material
	Steep learning curve
	One-step procedure
	Application of chondrocytes
	Arthroscopic application possible
	Off-the-shelf application
Pitfalls	
	Limited availability
	Arthroscopic experience
	No short- or long-term data available
	Generation of fibrous tissue
	Conversion to open procedure
	Invasiveness

might provide sufficient movement of chondrocytes around cartilage fragments and subsequent multiplication and matrix production.³³ Bonasia et al.³⁴ reported that a paste-like appearance provides optimal biological surroundings.

Donor cartilage can be taken from the periphery of the existing lesion where it is necessary to debride into healthy cartilage with a stable 90° rim. Different publications have clearly described that such chondrocytes are viable and could be used for further transplantation.^{35,36}

The newly introduced AutoCart procedure was developed for an all-autologous cartilage regeneration. Small-diameter shaver devices are used for rapid highly standardized fragmentation into a paste-like appearance. Levinson et al.²⁵ reported that chondrocyte viability is not significantly affected. Enrichment with PRP aims to promote chondrocyte proliferation and differentiation, which is assumed to be beneficial for minced cartilage proliferation. Hahn et al.³⁷ have recently shown that chondrocytes exhibit a significant dose- and time-dependent increase in cell number and metabolic cell activity when activated by PRP.

The technique presented in this article comes closest to the that reported by Cugat et al.³⁸ They treated full-thickness chondral or osteochondral defects with autologous cartilage chips embedded in a clot consisting of platelet-poor plasma and PRP in 15 patients. At 15 months postoperatively, improvements were seen in the International Knee Documentation Committee score, Western Ontario and McMaster Universities Osteoarthritis Index score, Lysholm score, visual analog scale score, and radiologic MOCART (Magnetic Resonance Observation of Cartilage Repair Tissue) score.³⁹

Concerning 1-stage solutions for the ankle, there are currently exclusively particulate juvenile articular allograft options available (particulate juvenile cartilage allograft transplantation [PJCAT]).¹⁷ This technique consists of immature live chondrocyte cells within their native extracellular matrix from donors typically younger than 13 years. Fibrin adhesive is used to secure these cartilaginous pieces within the subject's lesion.²¹

Coetzee et al.⁴⁰ published PJCAT outcome data in 23 patients (24 ankles), 14 of whom had at least 1 prior marrow stimulation failure, with 78% showing good to excellent scores on the American Orthopaedic Foot & Ankle Society Hindfoot Scale. Five patients required reoperation to remove symptomatic osteotomy hardware. During 3 of these reoperations, the International Cartilage Repair Society cartilage repair assessment (protocol A) was used to assess the repair tissue. The 3 lesions were deemed grade 2 (nearly normal repair), and 1 partial graft delamination (about 25% of the graft) was diagnosed at 16 months.⁷

Saltzman et al.²¹ conducted a study (review article) on 34 ankles with a mean follow-up period of 14.3 months. In 83.9% of the 31 ankles with clinical outcome data, substantial subjective improvements were reported. Five of these ankles required hardware removal because they were symptomatic or had osteotomy failure.

Dekker et al.⁴¹ performed PJCAT for the treatment of osteochondral lesions of the talus at a single institution. Failure was defined as no change in symptoms or worsening of symptoms and/or the need for an additional cartilage restoration procedure. The overall failure rate was 40%. In summary, the outcomes of various treatments are heterogeneous, with poor results and failures having been reported.³⁹

Further studies are required to clarify the extent to which allogeneic cells such as those mentioned earlier are at a disadvantage regarding the formation of hyaline tissue, but autologous approaches in the animal model showed a higher percentage of hyaline cartilage and fibrocartilage in the short term.⁴² The immunologic risks appear to be low with this technique, but studies in this regard are rare.⁷ Potential disadvantages specific to allografts include, furthermore, the theoretical risk of disease transmission. An important matter that requires further knowledge is fixation techniques. The aforementioned studies used fibrin glue for construct fixation. However, several animal studies have shown the negative effects of fibrin on cell migration and tissue repair.^{43,44} Moreover, there is the possibility that exogenous fibrin may induce an immune response.⁴⁵

Table 2. Advantages and Disadvantages of Minced Cartilage Implantation at Talus

Advantages	
	Inexpensive
	Stable transplantation technique
	No perpendicular approach needed
	Little donor-site morbidity
Disadvantages	
	Potential age limitation
	Application of dry field demanding
	Incomplete filling of defect
	Manufacturing of chondral particles

Irwin et al.⁴⁶ reported good stability of autologous thrombin, which results in natural fibrin when combined with PRP or platelet-poor plasma. Therefore, an autologous thrombin solution in the AutoCart procedure is assumed to increase stability without the aforementioned negative effects on cell differentiation.

Autologous minced cartilage repair is a 1-step approach that does not require manipulation in the laboratory or the use of allografts. It is therefore economically attractive and should not require significant regulations, as other procedures might.

We expect mechanically high-quality tissue and few or no biological effects associated with foreign bodies. Overall, the described technique is easy for the experienced arthroscopist to implement, reproducible, and safe to use. This technique has several clear advantages: It represents a single-stage procedure with a shallow learning curve without donor-site morbidity, it does not require graft contouring, and the need for a perpendicular access path to the defect bed is eliminated (unlike when using osteochondral plugs). Pearls and pitfalls are summarized in Table 1, and advantages and disadvantages are summarized in Table 2.

References

- Sorrento DL, Mlodzienski A. Incidence of lateral talar dome lesions in SER IV ankle fractures. *J Foot Ankle Surg* 2000;39:354-358.
- Takao M, Uchio Y, Naito K, Fukazawa I, Ochi M. Arthroscopic assessment for intra-articular disorders in residual ankle disability after sprain. *Am J Sports Med* 2005;33:686-692.
- van Buecken K, Barrack RL, Alexander AH, Ertl JP. Arthroscopic treatment of transchondral talar dome fractures. *Am J Sports Med* 1989;17:350-355. discussion 355-356.
- Hunziker EB, Kapfinger E. Removal of proteoglycans from the surface of defects in articular cartilage transiently enhances coverage by repair cells. *J Bone Joint Surg Br* 1998;80:144-150.
- Aurich M, Albrecht D, Angele P, et al. Behandlung osteochondraler Läsionen des Sprunggelenks: Empfehlungen der Arbeitsgemeinschaft Klinische Geweberegeneration der DGOU. *Z Orthop Unfall* 2017;155:92-99 [in German].
- Waizy H, Weber C, Berthold D, Vogt S, Arbab D. Osteochondrale Läsionen des Talus. *Arthroscopie* 2018;31:104-110 [in German].
- Wixted CM, Dekker TJ, Adams SB. Particulated juvenile articular cartilage allograft transplantation for osteochondral lesions of the knee and ankle. *Expert Rev Med Devices* 2020;17:235-244.
- Rothrauff BB, Murawski CD, Anghong C, et al. Scaffold-based therapies: Proceedings of the International Consensus Meeting on Cartilage Repair of the Ankle. *Foot Ankle Int* 2018;39:41S-47S (suppl).
- Pinski JM, Boakye LA, Murawski CD, Hannon CP, Ross KA, Kennedy JG. Low level of evidence and methodologic quality of clinical outcome studies on cartilage repair of the ankle. *Arthroscopy* 2016;32:214-222.e1.
- Niemeyer P, Albrecht D, Andereya S, et al. Autologous chondrocyte implantation (ACI) for cartilage defects of the knee: A guideline by the working group "Clinical Tissue Regeneration" of the German Society of Orthopaedics and Trauma (DGOU). *Knee* 2016;23:426-435.
- Kreuz PC, Erggelet C, Steinwachs MR, et al. Is microfracture of chondral defects in the knee associated with different results in patients aged 40 years or younger? *Arthroscopy* 2006;22:1180-1186.
- Carney D, Chambers MC, Boakye L, Amendola N, Yan AS, Hogan MV. Osteochondral lesions of the talus. *Oper Tech Orthop* 2018;28:91-95.
- Looze CA, Capo J, Ryan MK, et al. Evaluation and management of osteochondral lesions of the talus. *Cartilage* 2017;8:19-30.
- Christensen BB. Autologous tissue transplantations for osteochondral repair. *Dan Med J* 2016;63:B5236.
- Riboh JC, Cole BJ, Farr J. Particulated articular cartilage for symptomatic chondral defects of the knee. *Curr Rev Musculoskelet Med* 2015;8:429-435.
- Massen FK, Inauen CR, Harder LP, Runer A, Preiss S, Salzmänn GM. One-step autologous minced cartilage procedure for the treatment of knee joint chondral and osteochondral lesions: A series of 27 patients with 2-year follow-up. *Orthop J Sports Med* 2019;7. 2325967119853773.
- Harris JD, Frank RM, McCormick FM, Cole BJ. Minced cartilage techniques. *Oper Tech Orthop* 2014;24:27-34.
- Shah SS, Mithoefer K. Scientific developments and clinical applications utilizing chondrons and chondrocytes with matrix for cartilage repair. *Cartilage* 2020: 1947603520968884.
- Salzmänn GM, Calk A-K, Preiss S. Second-generation autologous minced cartilage repair technique. *Arthrosc Tech* 2017;6:e127-e131.
- Adams SB, Demetracopoulos CA, Parekh SG, Easley ME, Robbins J. Arthroscopic particulated juvenile cartilage allograft transplantation for the treatment of osteochondral lesions of the talus. *Arthrosc Tech* 2014;3:e533-e537.
- Saltzman BM, Lin J, Lee S. Particulated juvenile articular cartilage allograft transplantation for osteochondral talar lesions. *Cartilage* 2017;8:61-72.
- Dekker TJ, Steele JR, Federer AE, Easley ME, Hamid KS, Adams SB. Efficacy of particulated juvenile cartilage allograft transplantation for osteochondral lesions of the talus. *Foot Ankle Int* 2018;39:278-283.
- Cunningham DJ, Adams SB. Arthroscopic treatment of osteochondral lesions of the talus with microfracture and platelet-rich plasma-infused micronized cartilage allograft. *Arthrosc Tech* 2020;9:e627-e637.
- Cole BJ, Farr J, Winalski CS, et al. Outcomes after a single-stage procedure for cell-based cartilage repair: A prospective clinical safety trial with 2-year follow-up. *Am J Sports Med* 2011;39:1170-1179.
- Levinson C, Cavalli E, Sindi DM, et al. Chondrocytes from device-minced articular cartilage show potent outgrowth into fibrin and collagen hydrogels. *Orthop J Sports Med* 2019;7:2325967119867618.
- D'Hooghe P, Murawski CD, Boakye LAT, et al. Rehabilitation and return to sports: Proceedings of the International Consensus Meeting on Cartilage Repair of the Ankle. *Foot Ankle Int* 2018;39:61S-67S (suppl).

27. Salzmann GM, Ossendorff R, Gilat R, Cole BJ. Autologous minced cartilage implantation for treatment of chondral and osteochondral lesions in the knee joint: An overview [published online November 6, 2020]. *Cartilage*. <https://doi.org/10.1177/1947603520942952>.
28. Uozumi H, Sugita T, Aizawa T, Takahashi A, Ohnuma M, Itoi E. Histologic findings and possible causes of osteochondritis dissecans of the knee. *Am J Sports Med* 2009;37:2003-2008.
29. McCormick F, Yanke A, Provencher MT, Cole BJ. Minced articular cartilage—Basic science, surgical technique, and clinical application. *Sports Med Arthrosc Rev* 2008;16:217-220.
30. McNickle AG, Provencher MT, Cole BJ. Overview of existing cartilage repair technology. *Sports Med Arthrosc Rev* 2008;16:196-201.
31. Farr J, Cole BJ, Sherman S, Karas V. Particulated articular cartilage: CAIS and DeNovo NT. *J Knee Surg* 2012;25:23-29.
32. Lind M, Larsen A. Equal cartilage repair response between autologous chondrocytes in a collagen scaffold and minced cartilage under a collagen scaffold: An in vivo study in goats. *Connect Tissue Res* 2008;49:437-442.
33. Wang N, Grad S, Stoddart MJ, et al. Particulate cartilage under bioreactor-induced compression and shear. *Int Orthop* 2014;38:1105-1111.
34. Bonasia DE, Marmotti A, Mattia S, et al. The degree of chondral fragmentation affects extracellular matrix production in cartilage autograft implantation: An in vitro study. *Arthroscopy* 2015;31:2335-2341.
35. Biant LC, Bentley G. Stem cells and debrided waste: Two alternative sources of cells for transplantation of cartilage. *J Bone Joint Surg Br* 2007;89:1110-1114.
36. Chaipinyo K, Oakes BW, van Damme M-PI. The use of debrided human articular cartilage for autologous chondrocyte implantation: Maintenance of chondrocyte differentiation and proliferation in type I collagen gels. *J Orthop Res* 2004;22:446-455.
37. Hahn O, Kieb M, Jonitz-Heincke A, Bader R, Peters K, Tischer T. Dose-dependent effects of platelet-rich plasma powder on chondrocytes in vitro. *Am J Sports Med* 2020;48:1727-1734.
38. Cugat R, Alentorn-Geli E, Navarro J, et al. A novel autologous-made matrix using hyaline cartilage chips and platelet-rich growth factors for the treatment of full-thickness cartilage or osteochondral defects: Preliminary results. *J Orthop Surg (Hong Kong)* 2020;28:2309499019887547.
39. Christensen BB, Olesen ML, Hede KTC, Bergholt NL, Foldager CB, Lind M. Particulated cartilage for chondral and osteochondral repair: A review. *Cartilage* 2020:1947603520904757.
40. Coetzee JC, Giza E, Schon LC, et al. Treatment of osteochondral lesions of the talus with particulated juvenile cartilage. *Foot Ankle Int* 2013;34:1205-1211.
41. Dekker TJ, Steele JR, Federer AE, Hamid KS, Adams SB. Use of patient-specific 3D-printed titanium implants for complex foot and ankle limb salvage, deformity correction, and arthrodesis procedures. *Foot Ankle Int* 2018;39:916-921.
42. Ao Y, Li Z, You Q, Zhang C, Yang L, Duan X. The use of particulated juvenile allograft cartilage for the repair of porcine articular cartilage defects. *Am J Sports Med* 2019;47:2308-2315.
43. Brittberg M, Sjögren-Jansson E, Lindahl A, Peterson L. Influence of fibrin sealant (Tisseel) on osteochondral defect repair in the rabbit knee. *Biomaterials* 1997;18:235-242.
44. van Susante JL, Buma P, Schuman L, Homminga GN, van den Berg WB, Veth RP. Resurfacing potential of heterologous chondrocytes suspended in fibrin glue in large full-thickness defects of femoral articular cartilage: An experimental study in the goat. *Biomaterials* 1999;20:1167-1175.
45. Kawabe N, Yoshinao M. The repair of full-thickness articular cartilage defects. Immune responses to reparative tissue formed by allogeneic growth plate chondrocyte implants. *Clin Orthop Relat Res* 1991;268:279-293.
46. Irwin RM, Bonassar LJ, Cohen I, et al. The clot thickens: Autologous and allogeneic fibrin sealants are mechanically equivalent in an ex vivo model of cartilage repair. *PLoS One* 2019;14:e0224756.