



Cartiform Implantation for focal cartilage defects in the knee: A 2-year clinical and magnetic resonance imaging follow-up study

Craig H. Bennett, M.D.^{a,c,*}, Vidushan Nadarajah, M.D.^b, Michelle C. Moore, M.D., M.S.^a, Julio J. Jauregui, M.D.^a, Andrew G. Dubina, M.D.^a, Cameran Burt, B.S.^a, Derik L. Davis, M.D.^e, Arvinder Uppal, M.D.^d, R. Frank Henn III, M.D.^a

^a Department of Orthopaedics, University of Maryland School of Medicine, Baltimore, MD, USA

^b Department of Orthopaedic Surgery and Rehabilitation, SUNY Health Sciences University, Brooklyn, NY, USA

^c LifeBridge Health Sports Medicine Institute, Owings Mills, MD, USA

^d Charter Radiology, Columbia, MD, USA

^e Department of Diagnostic Radiology & Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, USA

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ABSTRACT

The purpose of this study was to evaluate clinical and magnetic resonance imaging (MRI) outcomes in patients who underwent cryopreserved viable osteochondral allograft (CVOCA) implantation for focal cartilage defects in the knee at a minimum of 2-years postoperatively. This is a retrospective follow-up study of twelve patients who underwent CVOCA implantation from 2013 to 2015 by a single surgeon for a International Cartilage Repair Society (ICRS) grade 3 or 4 chondral defect. Patient-reported outcome (PRO) measurements and MRI were obtained 2-years postoperatively. Collected PRO measures included: International Knee Documentation Committee (IKDC) form; Visual Analog Scale (VAS) pain score; Veterans RAND 12-Item Health Survey (VR-12); Knee Injury and Osteoarthritis Outcome Score (KOOS); and Western Ontario McMaster Universities Osteoarthritis Index (WOMAC). Patients completed a standard return to work and sports/recreation survey. A blinded, fellowship-trained musculoskeletal radiologist independently evaluated each MRI to determine the Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) score. Mean follow-up was 2.1 years (2.0–2.3). There were 6 women and 6 men with a mean age of 46.2 ± 11.9 years. Mean PRO scores were: IKDC 72.6 ± 17.4 ; VAS 2.9 ± 2.8 ; WOMAC 84.2 ± 15.1 ; KOOS- Pain 83.8 ± 18.5 , Symptoms 77.6 ± 16.0 , ADL 88.0 ± 16.9 , Sports/Rec 67.7 ± 33.3 , QOL 54.8 ± 24.2 ; and VR-12 PCS 45.0 ± 8.5 and MCS 51.1 ± 9.5 . The mean MOCART score was 59.5 ± 12.9 . To our knowledge, this is the largest study to report clinical and MRI outcomes of CVOCA implantation in the knee. With positive functional outcomes and lack of failures at 2-year follow-up, CVOCA is a promising treatment option for focal chondral defects in the knee.

Study design: Retrospective case series, Level of evidence 4.

1. Introduction

The rise in sports participation in the young and middle-aged population has led to an increased prevalence and incidence of focal articular cartilage defects in these patients.^{1–3} The management of articular cartilage defects presents one of the most challenging clinical problems for orthopaedic surgeons. Given the limited potential for intrinsic healing of articular cartilage, these patients are at an increased risk of debilitating joint pain, dysfunction, and degenerative arthritis.^{2–8} Current cartilage restoration procedures include marrow stimulation (e.g.

microfracture), autologous surface cellular procedures such as autologous chondrocyte implantation (ACI) and matrix-associated chondrocyte implantation (MACI), allograft surface cellular procedures (e.g. particulated juvenile articular cartilage and micronized adult articular cartilage), osteochondral autograft transfer system (OATS) procedure and osteochondral allograft (OCA) implantation.^{4,9–17} Each restoration technique has its own advantages and disadvantages.^{4,18}

The management of larger defects ($>2 \text{ cm}^2$), International Cartilage Repair Society (ICRS) Grade 3 ($>50\%$ articular cartilage) and Grade 4 (full-thickness defect extending to the subchondral bone), presents

* Corresponding author. 10084 Reisterstown Road, Suite 300A, Foundry Row, Owings Mills, MD, 21117.

E-mail addresses: drcbennett@gmail.com (C.H. Bennett), vidushannadarajah@gmail.com (V. Nadarajah), fhenn@som.umaryland.edu (R.F. Henn).

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specific challenges. For example, the donor-site morbidity associated with OATS limits the cartilage defect size that can be treated. ACI/MACI involves a minimum of two surgeries, one for tissue harvest and the other for cell implantation. ACI/MACI procedures are very expensive, and complications related to graft implantation such as tissue hypertrophy have been reported, particularly with ACI.^{19–22} Patients who have uncontained, inaccessible, multiple, or very large lesions; subchondral sclerosis; or advanced degenerative changes are not typically suitable candidates for MACI implantation. Additionally, the timeline for return to running and to full sports is extensive.^{23–25}

Fresh OCA implantation is a cartilage restoration procedure that involves the implantation of a cadaver graft consisting of intact articular cartilage and its subchondral bone into the defect. Advantages of the procedure include immediate implantation in a single surgery, lack of donor-site morbidity, and the ability to restore large defects, including those with poor containment. Fresh OCA allograft offers the advantage of implanting refrigerated cartilage with viable chondrocytes. The disadvantages of fresh OCA include the increased potential of disease transmission, the immune response to the subchondral bone, a moderate frequency of reactive synovitis, graft cost, graft availability, and surgical time constraints given graft expiration within a few weeks.²⁶

Several studies have been performed to assess the outcomes of the above procedures, but there is little data evaluating the use of cryopreserved OCAs. Cartiform (Arthrex; Naples, FL) is a cryopreserved viable osteochondral allograft (CVOCA) that is a surface graft. Advantages of CVOCA include a shelf life of 2 years when stored at -80°C , ease of implantation, and favorable cost and accessibility in comparison to fresh OCA and ACI/MACI.^{27–29} Additionally, the grafts can be used with moderately and poorly contained lesions. When the subchondral bone is involved, bone graft can be placed deep to the graft prior to implantation in the same stage.

The purpose of this study is to evaluate both the clinical and MRI outcomes of patients who have undergone CVOCA implantation for the treatment of ICRS Grade 3 and 4 cartilage defects in the knee 2-years postoperatively. We hypothesized that CVOCA will provide a successful surgical treatment for high-grade, focal articular cartilage defects of the knee, with minimal failure rates, both clinically and radiographically.

2. Methods

2.1. Patient selection

After institutional review board approval (HP-00066115), we retrospectively identified all patients who underwent CVOCA implantation by the senior surgeon (CHB) at a single center from 2013 to 2015. Patients who underwent concomitant surgery to the knee where the CVOCA was implanted were also included. Many of these patients had undergone concomitant meniscal or ligament surgery. These patients were included, as it is important to understand the results of CVOCA implantation both with and without injury to the supporting structures in the knee. Inclusion criteria for patients were: (1) age 18 years or older; (2) who underwent CVOCA implantation by the senior surgeon (CHB) between 2013 and 2015; (3) with up to 2 full-thickness (ICRS grades 3 and 4) cartilage lesions of the knee; (4) with localized knee pain unresponsive to nonoperative treatment and/or previous surgical intervention; (5) patients who were willing and able to consent to participate in the study; (6) patients able to safely undergo MRI at a minimum of 2-years postoperatively; (7) patients who had adequate data in their medical charts for review. Exclusion criteria were: (1) pregnancy or patients planning on becoming pregnant at the time of scheduled MRI follow-up; (2) septic or reactive arthritis or systemic disease; (3) deficiency limiting ability to perform an objective functional assessment of the operative knee.

2.2. CVOCA operative technique

2.2.1. Patient set up and preparation

The patient is placed in a supine position. A femoral nerve block is performed followed by a detailed knee examination under anesthesia. A thigh-high tourniquet is applied but is not used unless there is unexpected bleeding. The knee is injected with 30 cm^3 Marcaine and epinephrine.

2.2.2. Arthroscopy and debridement

The procedure begins with an arthroscopic cartilage lesion debridement. An abrasion chondroplasty is performed utilizing a barrel bur and a motorized shaver. A ring curette is used to remove unstable areas of peripheral articular cartilage. The abrasion is performed until there is visible punctate bleeding in the subchondral bone. For lesions greater than 1 cm in diameter, a microfracture is performed utilizing a microfracture awl. Microfracture punctures are placed at approximately 5 mm intervals and are not placed at anticipated future anchor insertion locations. Microfracture is not performed for 1 cm lesions.

2.2.3. Graft site preparation

Following defect site debridement, an open incision is made along the patellar tendon of the affected compartment. A midline incision is made when multiple compartments are involved. Bone wax is placed into the recipient site to contour the area of the defect and assist with size assessment. On the back table, the bone wax is then placed over the CVOCA graft to assist with contouring of the graft to fit the recipient defect. A No. 15 blade and/or suture scissors are used to appropriately contour the CVOCA graft. The bone side of the CVOCA graft is identified and marked with a sterile pen. When subchondral debridement leaves a deep defect greater than 2 mm below the initial cartilage surface level, autograft cancellous bone is used to fill the defect. The autograft bone is harvested from the ipsilateral proximal tibia or the ipsilateral distal femur.

2.2.4. Graft implantation

A 2-0 or 0 Vicryl suture is placed through the islet of a 12 mm, absorbable, biocomposite PushLock (Arthrex; Naples, FL). For the 1 cm lesions, a single suture anchor is placed in the center of the defect. For the 1 cm lesions with extremely stable edges the CVOCA is press fit and no suture is required. For lesions larger than 1 cm utilizing the 2 cm CVOCA graft, between two and four Vicryl sutures with supporting anchors are placed based on the shape and size of the defect. For circular, near 2 cm lesions, three peripheral sutures are placed in a triangular fashion. For poorly contained lesions, four sutures are placed in a four-quadrant configuration.

Suture anchors are used as they provide definitive fixation. Peripheral suturing of the CVOCA to the native articular cartilage is not performed unless peripheral stability is needed. No cases in this review required peripheral sutures. The peripheral cartilage can be difficult to suture secondary to fragility or density.

A Keith needle is used to thread the Vicryl suture which has been inserted in the subchondral bone through the CVOCA graft at the appropriate positions. Prior to securing the graft to the recipient site, autograft bone is placed into the defect when required. The sutures are tied at the surface of the CVOCA graft using simple knots. Once graft stability has been assured, a few cubic centimeters of autograft leukocyte-low PRP are injected if the patient has agreed to cover the cost of the PRP and no tunnel drilling for cruciate ligament surgery has been performed. Fibrin glue is then placed at the periphery of the repair. The amount of fibrin glue is minimized to limit the potential of adherence to the fat pad. Following wound closure, a compressive cold device and brace are applied. Fig. 1 depicts the procedure steps outlined above.

2.2.5. Postoperative rehabilitation

Phase 1 begins immediately postoperatively and extends for the first

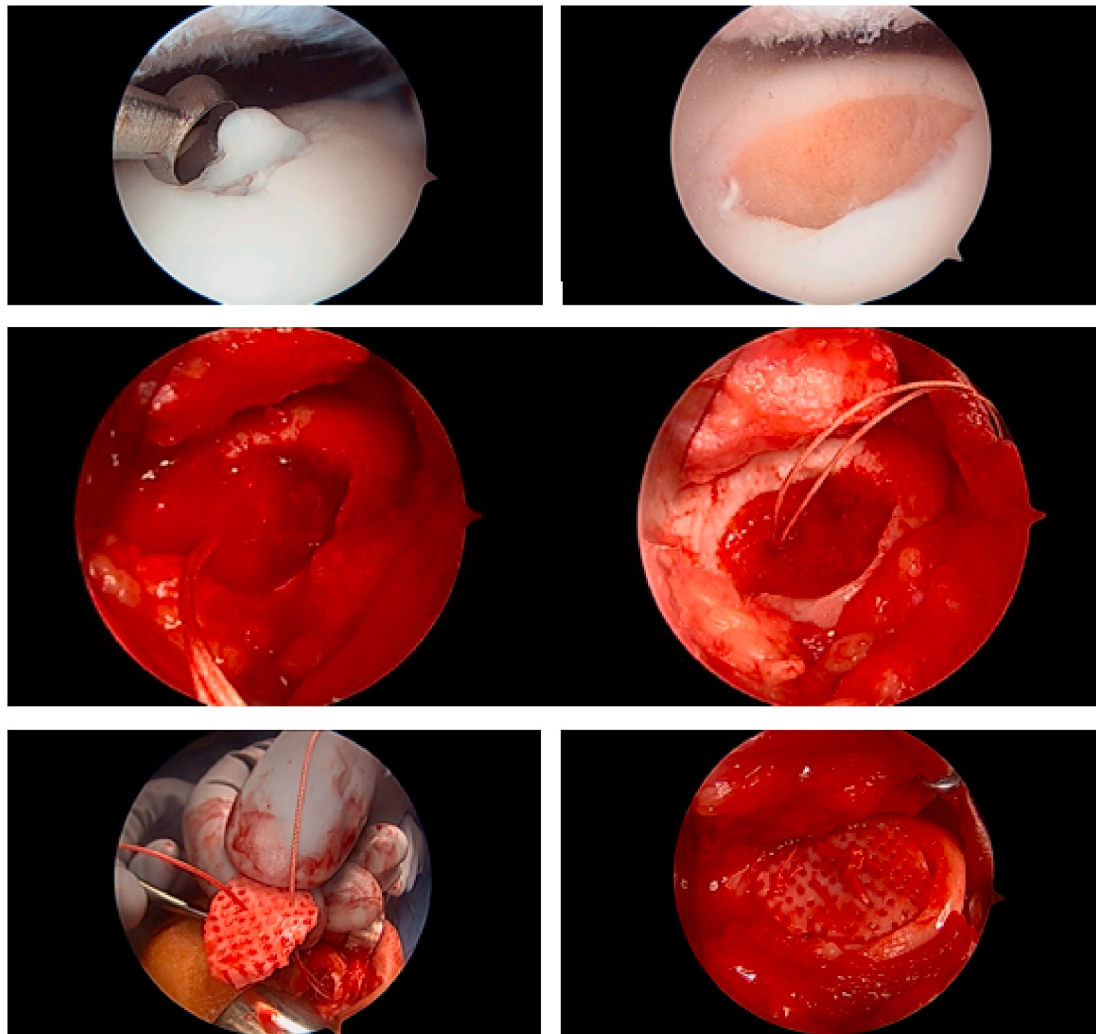


Fig. 1. Arthroscopic images of cartiform implantation.

two weeks. The range of motion goals are to maintain terminal extension and initiate flexion to 90° . The graft is allowed to settle for three days and flexion begins on postoperative day three. Goals of this stage are to promote healing of the wound, protect the graft, limit the potential of deep venous thrombosis, and limit the potential for knee fibrosis. A long leg, hinged brace is locked in full extension for sleeping and for ambulation. The brace is removed for range of motion exercises. A continuous passive motion machine (CPM) is used beginning on postoperative day three. The CPM is used for 1 h, three times per day, beginning at $0\text{--}45^\circ$ and increasing at 15° per day to achieve 90° of flexion. Weight-bearing is toe touch with two crutches and the brace locked in extension. Therapeutic exercises performed three times per day are ankle pumps, knee extension exercises, patellar mobilization performed passively and quadriceps isometrics.

Phase 2 begins two weeks postoperatively and extends to five to six weeks postoperatively. The criteria for advancement to this phase include limited inflammation and flexion to at least 75° . Weight-bearing remains toe touch with two crutches but with the brace being unlocked for range to 45° . Therapeutic exercises include those from phase 1. Additional exercises include heel slides with assistance from the opposite leg, prone hangs to promote knee extension, straight leg raise exercises and hip abduction exercises.

Phase 3 begins five to six weeks postoperatively and extends to 11–12 weeks postoperatively. Criteria for advancement include a normal straight leg raise and flexion to at least 120° . Weight-bearing status progresses to full weight-bearing with two crutch support at

week five, transitioning to one crutch in the contralateral arm at week six. The goal is for crutches to be discontinued by the end of week six. For femoral condyle lesions, the patient is transitioned from the postoperative brace at week six to an unloader brace, presuming appropriate functional strength and a $0\text{--}120^\circ$ range of motion. With patellofemoral lesions the transition is to a short hinged sleeve. Therapeutic exercises include all exercises from phase 2 with the addition of wall slides, leg presses from 0 to 45° , three-way hip motion with progressive resistance, hamstring curls with progressive resistance and treadmill walking. Additionally, a stationary bike with no brace is used with no initial tension and a subsequent steady tension increase. When available, an aquatic program including pool running and straight leg kicking is performed.

Phase 4 begins 12 weeks postoperatively and extends to 25 weeks postoperatively. Criteria for advancement to phase 4 include full range of motion in conjunction with a normal gait. The goals are to improve strength and endurance in preparation for functional activities. Proprioceptive training is initiated while protecting the repair and protecting the patellofemoral joint. Therapeutic exercises performed every other day include all exercises from phase 3. Patients are progressed to single leg wall slides and leg presses to 90° of flexion. An elliptical trainer and/or a de-weighted running machine is used. For femoral condyle lesions, the appropriate unloader brace is used; a short hinged sleeve is used for patellofemoral lesions. Patients begin balance and proprioceptive training including usage of a balance board. Plyometric training is initiated and is performed on a dedicated soft and level surface.

Phase 5 begins 25 weeks postoperatively and extends to approximately one year postoperatively. Criteria for advancement to phase 5 include near symmetric thigh musculature with hamstrings and quadriceps strength within 90% of the opposite limb. The goals are to maximize strength, endurance and proprioception with minimization of swelling. Therapeutic exercises are performed every other day and with the brace. These include all exercises from phase 4. Additional exercises include initiation of jogging on any surface as tolerated with a gradual increase in distance and speed. Agility drills may be added after linear running is mastered. Sports specific training when needed begins when agility drills are performed appropriately.

2.2.6. Clinical evaluation

At a minimum of 2-years postoperatively, clinical and functional scores were collected for each participant. Collected patient-reported outcome (PRO) measures included: International Knee Documentation Committee (IKDC) subjective knee form; Visual Analog Scale (VAS) pain score; Veterans RAND 12 Item Health Survey (VR-12), which included the Physical Component Score (PCS) and Mental Component Score (MCS); Knee Injury and Osteoarthritis Outcome Score (KOOS), including the subscores: Pain, Symptoms, Activities of Daily Living (ADL), Sports and Recreation, and Quality of Life (QOL); and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score. Patients also completed a standard return to work and sports/recreation survey.

2.2.7. Magnetic resonance imaging

All imaging examinations were performed at 3.0 T (Magnetom Verio or Skyra; Siemens Healthcare, Erlangen, Germany) using a dedicated knee coil. The imaging protocol included standard two-dimensional (2D) turbo spin-echo (TSE) sagittal intermediate-weighted sequence, 2D TSE sagittal intermediate-weighted fat saturation sequence, 2D TSE coronal intermediate-weighted fat saturation sequence, 2D TSE coronal T1-weighted sequence, 2D TSE axial intermediate-weighted fat saturation sequence, and three-dimensional (3D) sagittal gradient echo fat saturation sequence (see Figs. 2 and 3). A blinded, fellowship-trained musculoskeletal radiologist independently evaluated each MRI to determine the Magnetic Resonance Observation of Cartilage Repair

Tissue (MOCART) scores for each participant.^{30,31} The MOCART score ranges from 0 to 100, with a score of 100 representing the best possible score. Failure of the procedure was defined as a reoperation resulting in removal of the implant, such as revision with fresh OCA implantation or arthroplasty.

2.2.8. Statistical analysis

Descriptive statistics included frequencies, means, standard deviations, and ranges where appropriate. Spearman's correlation coefficients were used to assess correlation between patient-reported outcome measures (IKDC, KOOS, VR-12, etc.) and the MOCART total score. Statistical analysis was performed using JMP Pro, Version 14 software (JMP®, Version 14. SAS Institute Inc., Cary, North Carolina).

3. Results

Twelve patients who underwent CVOCA implantation between 2013 and 2015 by the senior surgeon (CHB) satisfied the inclusion and exclusion criteria for this study and were available for follow-up. The mean follow-up was 2.1 years (range, 2.0–2.3 years). Participant demographics are provided in Table 1. There were 6 females and 6 males with a mean age of 46.2 years (range, 28.2–59.2). Ten patients participated in recreational sports, 3 patients were competitive sport athletes, and 5 patients were runners. The average American Society of Anesthesiologists (ASA) Score was 1.7 (range, 1–3).

All patients had reconstructed chondral lesions that were ICRS grade 3 or 4. Two patients had isolated lesions of the medial femoral condyle (MFC). One patient had an isolated lesion of the lateral femoral condyle (LFC). One patient had an isolated lesion of the trochlea. The remaining patients had two compartment chondral lesions of ICRS grade ≥ 3 . All patients received CVOCA in exclusively one compartment, that being the most symptomatic or clinically pronounced area. The remaining compartments with ICRS grade ≥ 3 changes were treated with chondroplasty or abrasion chondroplasty. One patient (patient 6) who received a CVOCA to the MFC was also treated with a micronized adult allograft (BioCartilage; Arthrex) into an ICRS grade 4 lateral tibial plateau lesion. The average post debridement defect size for the graft recipient site was

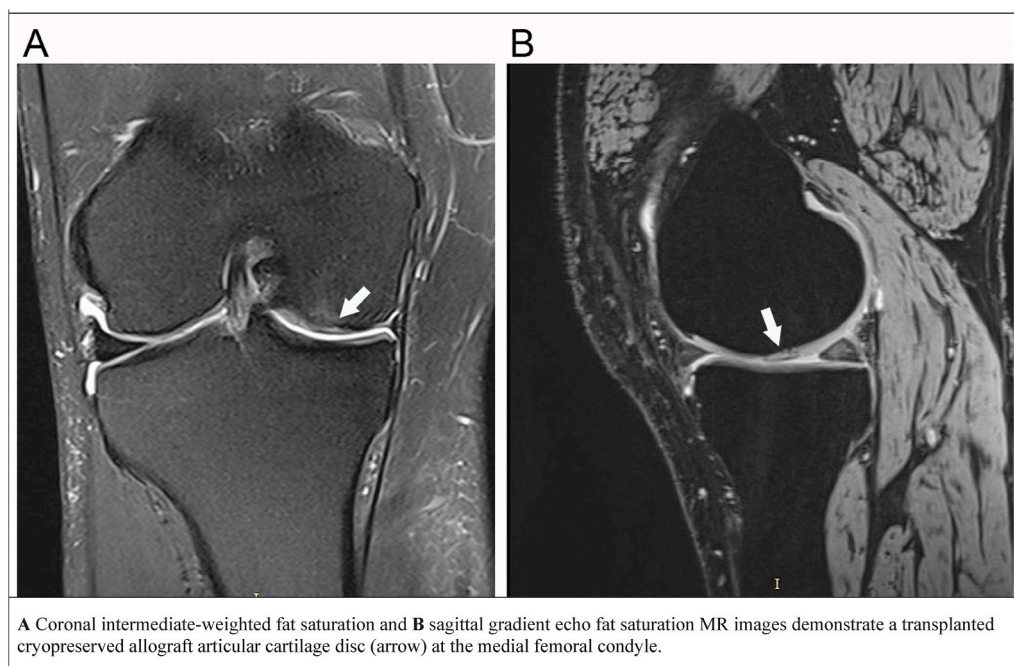
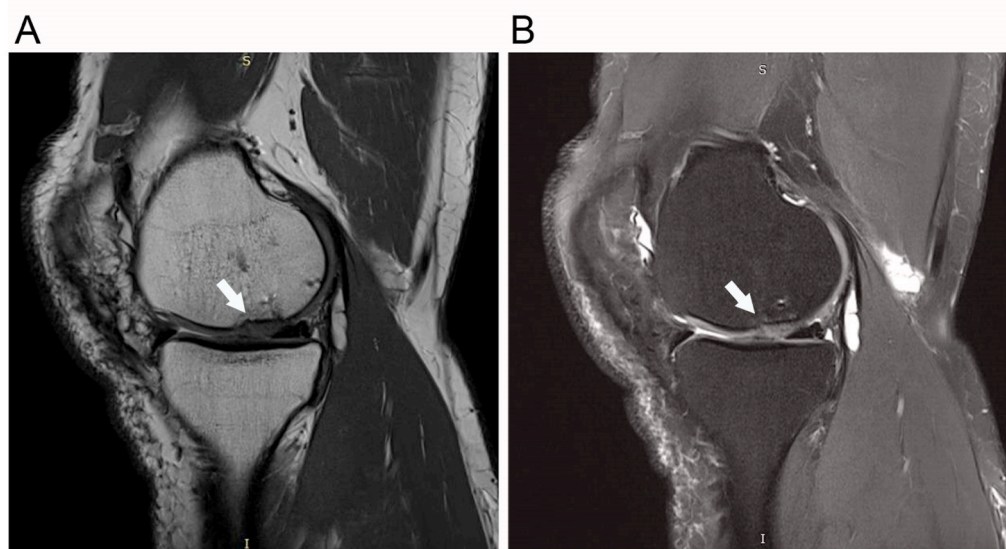


Fig. 2. Cartiform Implantation

A Coronal intermediate-weighted fat saturation and B sagittal gradient echo fat saturation MR images demonstrate a transplanted cryopreserved allograft articular cartilage disc (arrow) at the medial femoral condyle.



A sagittal intermediate-weighted and B sagittal intermediate-weighted fat saturation MR images demonstrate a Cartiform cryopreserved allograft articular cartilage disc (arrow) following transplantation at the medial femoral condyle.

Fig. 3. Cartiform Implantation

A sagittal intermediate-weighted and B sagittal intermediate-weighted fat saturation MR images demonstrate a Cartiform cryopreserved allograft articular cartilage disc (arrow) following transplantation at the medial femoral condyle.

Table 1

Patient demographics.

Patient No.	Gender	Race	Age (years)	BMI (kg/m ²)	Follow-Up (years)	ASA	Recreational Sports/Activity	Competitive Sports	Runner
1	Female	Black	55.2	39.9	2.2	2	Yes	No	Yes
2	Male	White	58.2	28.5	2.2	3	Yes	No	Yes
3	Female	White	51.7	40.9	2.2	1	Yes	No	No
4	Female	White	59.2	27.8	2.2	2	Yes	No	No
5	Male	White	33.3	30.8	2.1	1	Yes	Yes	Yes
6	Female	White	46.0	30.8	2.3	1	Yes	Yes	Yes
7	Female	Black	53.2	33.0	2.2	2	Yes	No	No
8	Male	White	28.2	27.3	2.1	1	Yes	Yes	Yes
9	Male	White	48.7	29.5	2.1	2	Yes	No	No
10	Female	White	57.8	27.6	2.3	2	No	No	No
11	Male	White	28.8	25.2	2.0	1	Yes	No	No
12	Male	White	34.2	25.6	2.3	2	Yes	No	Yes
Mean (± SD)			46.2 ± 11.9	30.6 ± 5.1	2.1 ± 0.3	1.7 ± 0.7			
Range			28.2–59.2	25.2–40.9	2.0–2.3	1.0–3.0			

2.4 cm² (range, 0.9–4.8 cm²), and the average graft size was 2.4 cm² (range, 1.0–4.8 cm²). Two patients had poorly contained lesions. Patient 6 had loose grade 3 and grade 4 chondral damage of the entirety of the main weight bearing portion of the medial femoral condyle. The LFC lesion in patient 12 demonstrated unstable grade 3 cartilage flap tearing. See Table 2, which outlines the graft compartment location, the defect and graft area size and concomitant procedures.

For 11 of the 12 patients the CVOCA procedure was their index cartilage grafting procedure. One patient (patient 11) had a previous 1-cm fresh OCA implantation into the medial femoral condyle; the CVOCA for this patient was placed into a trochlear lesion. For two patients, the CVOCA implantation was an isolated knee procedure. The remaining patients underwent CVOCA implantation with concomitant procedures to the knee. No patients were treated with osteotomies. None of the CVOCA procedures were performed in a bipolar manner. However, one patient with an MFC CVOCA graft had an ICRS grade 3 kissing lesion in the medial tibial plateau. One patient treated with a trochlear CVOCA graft had ICRS grade 3 patellar changes.

Regarding augmentation to the graft implantation site, three patients were treated with bone graft deep to the CVOCA implant. Abrasion chondroplasties were performed in all implant recipient sites. All grafts

were fixed via a suture anchor or suture anchors preceded by drill hole placement into the subchondral bone. Additional microfractures were performed at the recipient sites for ten of the twelve patients. Two of the patients who received 1-cm grafts had subchondral abrasions without microfracture. Autologous leukocyte low PRP injections were performed at the graft site in five cases. Patient 7 was taken back to the operating room 20 months after MFC CVOCA implantation for continued lateral knee pain and underwent an arthroscopic debridement to the lateral tibial plateau. The patient was asymptotic on the medial aspect of the knee, and the medial CVOCA graft site was well incorporated at the time of the second look arthroscopy (see Fig. 4). The patient's lateral knee symptoms improved following the second procedure.

3.1. Concomitant procedures

3.1.1. Major concomitant procedures

Patient 5 underwent a concomitant autograft hamstrings anterior cruciate ligament reconstruction. Patient 9 received a CVOCA graft to the MFC and underwent an all-inside medial meniscus repair for a bucket handle tear. Patient 12, who received a CVOCA graft to the LFC, also underwent an allograft medial patellofemoral ligament (MPFL)

Table 2
Summary of cartilage defects and concomitant procedures.

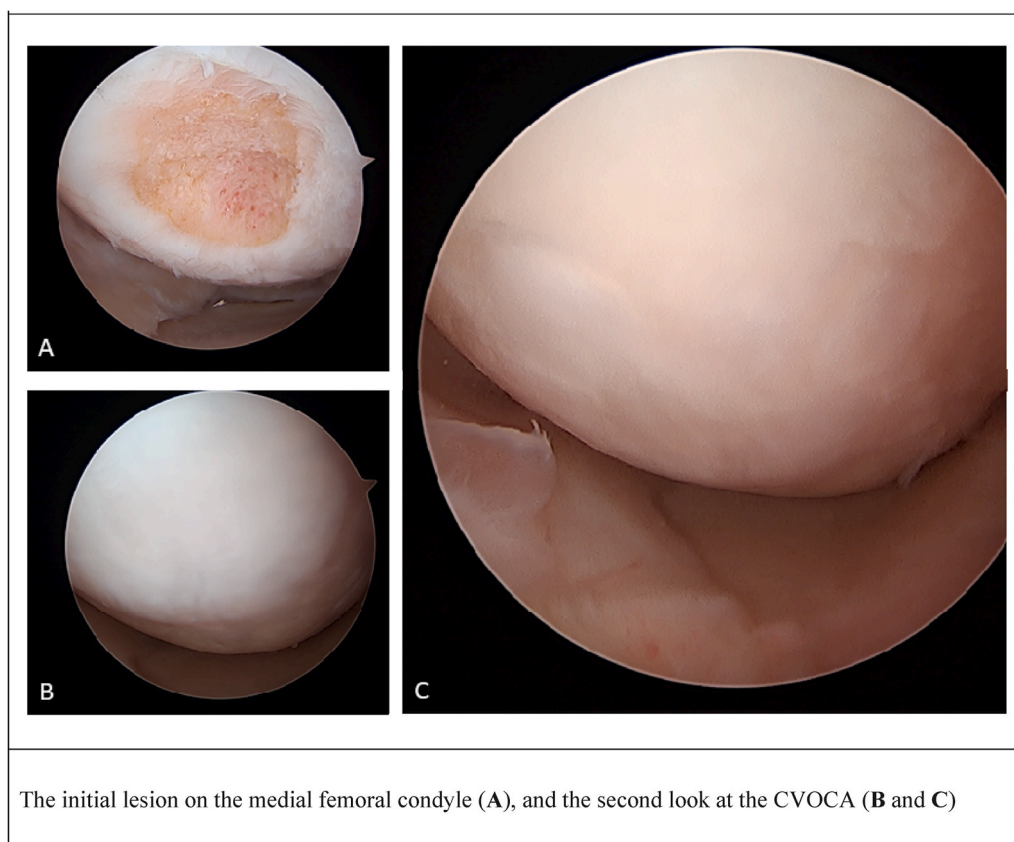
Patient No.	Lesion/Graft Location	Cartilage defect/graft area (cm ²)	PRP	Bone Graft	Concomitant Procedures	Lesion Contained
1	MFC	3			Partial medial meniscectomy Abrasion chondroplasty of LFC and trochlea	Yes
2	MFC	1			Partial medial meniscectomy	Yes
3	MFC	3.4	Yes		Abrasion chondroplasty of LFC	Yes
4	Trochlea	4	Yes	Yes	Abrasion chondroplasty lateral tibial plateau	Yes
5	MFC	1			^a ACL reconstruction Limited patella chondroplasty	Yes
6	MFC	4.8	Yes		^b BioCartilage to lateral tibial plateau	No
7	MFC	2.4			Chondroplasty of lateral tibial plateau ^b and medial patella	Yes
8	LFC	1				Yes
9	MFC	1.92	Yes	Yes	^a Medial meniscus repair	Yes
10	MFC	1			PRP into quadriceps tendon	Yes
11 ^c	Trochlea	2.25	Yes	Yes		Yes
12	LFC	3			^a MPFL reconstruction	No
Average ± SD (Range)		2.4 ± 1.2 (1–4.8)				

MFC: Medial Femoral Condyle; **LFC:** Lateral Femoral Condyle; **PRP:** Platelet Rich Plasma; **MPFL:** Medial Patellofemoral Ligament.
SD: Standard Deviation.

^a Major concomitant procedure.

^b This patient underwent a repeat knee arthroscopy.

^c This patient underwent a previous osteochondral allograft implantation in location of the lesion.



The initial lesion on the medial femoral condyle (A), and the second look at the CVOCA (B and C)

Fig. 4. Patient No. 7 – Second Look CVOCA

The initial lesion on the medial femoral condyle (A), and the second look at the CVOCA (B and C).

reconstruction. A trochlea CVOCA graft with a concomitant revision OATS procedure to the MFC was performed in patient 11. Patient 6 was treated with an MFC CVOCA graft as well as with micronized adult allograft cartilage into the lateral tibial plateau.

3.1.2. Moderate concomitant procedures

Two patients treated with CVOCA grafts to the MFC also had partial medial meniscectomies (patients 1 and 2). Three patients had abrasion

chondroplasties of knee compartments not receiving the CVOCA implant (patients 1, 3, and 4). Two patients had chondroplasty of ICRS grade 2 lesions in additional compartments (patients 5 and 7).

3.1.3. Postoperative clinical outcomes

Review of the return to work and sports/recreation survey demonstrated no CVOCA implant failures noted amongst study participants at 2-years postoperatively. Postoperative patient reported outcome scores

are reported in Table 3.

The mean IKDC function score was 72.6 ± 17.4 (normalized age and gender percentile: 35%, ± 21.3). The mean VAS pain score was 2.9 ± 2.8 . The mean WOMAC-total score was 84.2 ± 15.1 . The mean KOOS sub-scores were: Pain 83.8 ± 18.5 , Symptoms 77.6 ± 16.0 , ADL 88.0 ± 16.9 , Sports/Recreation 67.7 ± 33.3 , and QOL 54.8 ± 24.2 . The mean VR-12 Physical component score was 45.0 ± 8.5 and the mean VR-12 mental component score was 51.1 ± 9.5 .

3.1.4. MRI scores

In the 11 patients where MRI analysis was feasible, the overall MOCART scores ranged from 35 to 75, with a mean of 59.6 ± 12.9 . The 9 component score means were defect repair and filling 16.8 ± 4.6 , integration to border zone 9.5 ± 2.7 , repair tissue surface 5.0 ± 3.9 , repair tissue structure 0.0 ± 0.0 , subchondral lamina 2.3 ± 2.6 , subchondral bone 1.4 ± 2.3 , adhesions 4.6 ± 1.5 , synovitis/effusion 2.3 ± 2.6 , and signal intensity 17.7 ± 4.1 . The individual MOCART component and total scores for the 11 patients are reported in Table 4. There were no significant correlations observed between MOCART score and PROs scores (Table 3).

4. Discussion

This retrospective follow-up study of 12 patients at a minimum of 2 years after CVOCA implantation demonstrates satisfactory outcomes with respect to patient reported outcomes and MRI imaging. There were no reported complications or graft failures, and patients reliably returned to activity. One MFC graft patient (patient 7) underwent a successful repeat arthroscopy for pain in the lateral compartment. The average cartilage defect and graft size was 2.4 cm^2 (range, $0.9\text{--}4.8 \text{ cm}^2$), putting the areas of reconstruction on average into a moderately large category.

There are currently multiple cartilage restoration procedures for the management of ICRS grade 3 and 4 cartilage defects. There is no uniformity regarding surgical treatment for these lesions, particularly for smaller lesions. Autologous surface cellular procedures (ACI/MACI) and fresh OCA have been more widely accepted in treatment of lesions greater than 2 cm^2 ; these procedures have demonstrated results that are superior to microfracture for large lesions.^{18,32–34}

Despite their long term track records, the autologous surface cellular procedures (ACI/MACI) have practical disadvantages. The procedure involves two surgeries, one for cartilage tissue harvest and the other for cell implantation. The minimum timeframe for graft implantation after harvest is six weeks. ACI/MACI procedures are very expensive, with

costs exceeding \$30,000. Regarding tissue structure, complications related to graft implantation such as tissue hypertrophy have been reported, particularly with first and second generation ACI techniques.^{19–22} Also, the resulting tissue is hyaline-like and not purely hyaline.³⁵ Graft implantation requires the defect to be well contained. Additionally, the timeline for return to running and to full sports is extensive, with typical full sport recovery in the range of 12–18 months.^{23,36}

Fresh OCA offers the advantage of implanting viable chondrocytes in a single stage. An additional benefit is the ability to restore large defects, including those with poor containment. The biologic disadvantages of fresh OCA include the potential of disease transmission, the immune response to the subchondral bone and a moderate frequency of reactive synovitis.^{26,37–39} Recent studies have called into question the efficacy of graft pulse lavaging in reducing these reactions to the subchondral bone with these fresh grafts.⁴⁰ Practical concerns include graft cost, graft availability, and surgical timing constraints given a graft expiration time in weeks.^{41–43} Technical concerns include the need for precise restoration of the radius of curvature, and matching the graft surface height to the recipient site surface level.

Given these varied concerns, allograft surface cellular procedures have become increasingly utilized over the past decade. Popular examples include CVOCA, particulated juvenile articular cartilage (PJAC) and micronized adult articular cartilage. The advantages of Cartiform (CVOCA) over the latter two products are multiple, including the immediate transplantation of adult hyaline cartilage with organized architecture. The structural maintenance within the CVOCA has been shown to translate into properly oriented repair tissue. The preservation of the distinct superficial, translational and radial zones has been demonstrated upon histological analysis in a preclinical animal model and a clinical biopsy.^{27,44} Besides the biologic benefits, the structure allows for ease of handling, use in poorly contained lesions and earlier weight-bearing. When there is deep subchondral involvement, bone graft can be placed into the defect and the CVOCA graft can provide a full chondral surface covering. Particulated allograft procedures, in contrast, are not amenable to poorly contained and uncontained lesions. Additionally, the shelf life of CVOCA is two years, as opposed to a few weeks with PJAC.²⁹

While CVOCA fits into the aforementioned allograft surface category, it is also an osteochondral allograft. The thin layer of retained subchondral bone is applied to the recipient site at the time of implantation. CVOCA comparisons with fresh osteochondral allograft are noteworthy. The limited period of chondrocyte viability with fresh OCA presents a significant practical concern, affecting the timing and logistics of

Table 3
Postoperative patient-reported outcome measures.

Patient No.	IKDC	VAS	WOMAC (TOTAL)	KOOS Pain	KOOS Symptoms	KOOS ADL	KOOS Sport/ Rec	KOOS QOL	VR-12 PCS	VR-12 MCS
1	85.1	0.0	96.9	92.0	89.0	99.0	92.0	88.0	46.8	53.4
2	96.6	2.0	96.2	100.0	89.0	97.0	100.0	81.0	51.5	58.2
3	83.9	1.0	85.6	86.0	82.0	85.0	70.0	69.0	43.3	57.8
4	51.7	3.0	65.6	72.0	68.0	74.0	25.0	31.0	34.2	52.4
5	75.9	3.0	84.8	84.0	68.0	91.0	70.0	44.0	52.7	58.2
6	80.5	2.0	78.8	83.0	71.0	88.0	75.0	44.0	60.3	26.2
7	74.7	1.9	87.1	100.0	86.0	91.0	90.0	38.0	38.5	56.4
8	89.7	0.0	97.7	97.0	96.0	100.0	100.0	75.0	49.6	58.2
9	72.4	10.0	100.0	100.0	100.0	100.0	100.0	88.0	38.7	47.2
10	35.6	4.0	47.0	36.0	43.0	40.0	0.0	31.0	30.5	40.3
11	55.2	6.0	83.3	67.0	75.0	94.0	30.0	19.0	48.7	50.2
12	70.1	2.0	87.9	89.0	64.0	97.0	60.0	50.0	45.0	54.4
Mean (\pm SD)	72.6 \pm 17.4	2.9 \pm 2.8	84.2 \pm 15.1	83.8 \pm 18.5	77.6 \pm 16.0	88.0 \pm 16.9	67.7 \pm 33.3	54.8 \pm 24.2	45.0 \pm 8.5	51.1 \pm 9.5
Range	36–97	0–10	47–100	36–100	43–100	40–100	0–100	19–88	31–60	26–58
MOCART ρ	–0.12	0.52	–0.08	0.23	0.17	–0.09	0.21	–0.16	–0.14	–0.06
p value	0.74	0.10	0.82	0.49	0.61	0.80	0.54	0.63	0.68	0.87

The spearman’s correlation coefficient (ρ) for MOCAT score and each PRO is given with corresponding p value.

Table 4
MOCART scores.

Patient No.	Defect Repair and filling	Integration to Border Zone	Repair tissue surface	Repair tissue structure	Sub-chondral lamina	Sub-chondral bone	Adhesions	Synovitis/ Effusion	Signal Intensity	MOCART Total
1	15	10	5	0	0	0	5	0	10	45
2	20	10	10	0	5	5	5	0	20	75
3	10	15	0	0	0	0	5	0	15	45
5	20	10	5	0	5	0	5	0	20	65
6	20	10	5	0	0	0	5	0	20	60
7	10	10	10	0	5	0	5	5	25	70
8	20	5	0	0	5	0	5	5	15	55
9	20	10	5	0	0	5	5	5	20	70
10	20	10	10	0	5	5	0	5	15	70
11	20	10	5	0	0	0	5	5	20	65
12	10	5	0	0	0	0	5	0	15	35
Mean ± SD	16.8 ± 4.6	9.5 ± 2.7	5.0 ± 3.9	0.0 ± 0.0	2.3 ± 2.6	1.4 ± 2.3	4.5 ± 1.5	2.3 ± 2.6	17.7 ± 4.1	59.5 ± 12.9
Range	10–20	5–15	0–10	0–0	0–5	0–5	0–5	0–5	10–25	35–75

performing the surgery. Regarding fresh OCA, Allen et al.⁴¹ reported on the preservation of osteochondral biomechanical and matrix characteristics, but decreased chondrocyte density and metabolic activity in specimens stored for 21 days before implantation. Similarly, Pearsall et al.⁴² reported progressively less matrix staining with prolonged refrigeration. CVOCA, however, is a cryopreserved osteochondral allograft. Cryopreservation involves rate-controlled freezing of specimens in a nutrient rich, cryoprotectant medium to limit cellular freezing and preserve cell viability. In an animal model, Gole et al.⁴⁵ reported a 77% rate of chondrocyte viability at one year in cryopreserved osteochondral allografts implanted into load-bearing sites.

In addition to a greater shelf life, the CVOCA is a perforated implant, which allows for it to be trimmed and conformed to anatomically fit the defect and reduces the need for extensive preoperative templating and patient-specific sizing. From a technical standpoint, the implantation of a fresh OCA is more demanding than CVOCA application. This is particularly true in areas such as the posterior aspect of the lateral femoral condyle or in the tibial plateau. The flexibility of CVOCA makes its use very amenable in the trochlea, where the concave architecture can make fresh OCA implantation challenging.

CVOCA is generally less expensive than fresh OCA when treating lesions 4.5 cm² or smaller. Additionally, the requisite instrumentation and cost required for implementation is less pronounced. The approximate CVOCA cost ranges from \$3500 for 1 cm² of coverage to \$11,000 for 4.5 cm² of coverage. In contrast, a fresh hemicondyle costs approximately \$12,000. A fresh osteochondral allograft is less expensive per square centimeter, making it more cost effective for very large lesions.²⁹ Another option is a precut fresh OCA core, which is cheaper than a hemicondyle at approximately one-fifth of the price for a 10-mm core and two-fifths of the price for a 15-mm core.⁴⁶ However, studies have shown defect sizes to be underestimated by preoperative MRIs. Campbell et al.⁴⁷ reported that arthroscopic visualization showed a larger lesion than preoperative MRI estimates in 74% of patients. The MRI underestimated the area of the cartilage defect by 70% on average compared to the arthroscopic measurements.⁴⁷ If precut fresh OCA cores were ordered according to the preoperative MRI estimates, it may be an insufficient size and unusable for that case.

Limited CVOCA results exist in the present literature. Hoffman et al.²⁷ reported on the treatment of a singular trochlear defect with CVOCA implantation. At nine months, the patient demonstrated complete resolution of pain and improvement in function, and the repair tissue consisted of 85% hyaline cartilage. Repeat arthroscopy showed a well-integrated graft, and MRI showed an isointense graft as compared to the surrounding cartilage.²⁷ Vangsnæs et al.²⁹ reported satisfactory outcomes in a small retrospective case series of patients treated with CVOCA. Three patients who presented with articular cartilage lesions of more than 2 cm² were followed for up to 2 years after implantation. The

three patients had satisfactory clinical and MRI outcomes without adverse events.²⁹

There have been multiple short, intermediate and long-term reports on the results of patients who have received fresh osteochondral allografts.^{26,48–50} Several of these studies reported outcomes of fresh OCAs at a similar follow-up duration as our study. Wang et al.⁴⁸ reported a mean IKDC score increase from 45 to 63.6 in patients ≥40 years old undergoing fresh OCA implantation of focal cartilage lesions in the knee at a minimum 2-year follow-up and mean duration of follow-up of 3.6 years. LaPrade et al.⁴⁹ reported a mean IKDC increase from 52 to 68.5 at 3-year follow-up in patients undergoing refrigerated OCA implantation between fifteen and twenty-eight days after procurement. The mean postoperative IKDC for the patients in our study group was higher than the above fresh OCA comparisons at 72.6. McCulloch et al.⁵⁰ followed 25 patients after prolonged fresh OCA of the femoral condyle for an average follow-up of 35 months and reported statistically significant improvement in the IKDC scores from 29 to 58 and improvements in each KOOS subscore; Pain from 43 to 73, Symptoms from 46 to 64, ADL from 56 to 83, Sport/Recreation from 18 to 46, and QOL from 22 to 50.⁵⁰ Our study group had higher mean postoperative IKDC (72.6) and higher mean postoperative KOOS subscores (Pain 84.5, Symptoms 76.4, ADL 88.2, Sport/Recreation 65.0, QOL 56.9) compared to those reported by McCulloch et al. Fresh osteochondral allograft implantation is a time tested procedure, and more information is needed to assess whether cryopreserved allografts will demonstrate similar success and survivorship.

Regarding the MRI evaluations, MOCART is a reproducible semi-quantitative scoring system for the assessment of cartilage repair that has been widely used as an outcome measure for longitudinal clinical trials.^{51,52} While MOCART is ideal for assessing the repair site, determining correlations between the MOCART scores and clinical outcomes is difficult with this small case series. The study also included patients with various concomitant procedures, which affects their clinical outcome scores. There was no apparent correlation between the MOCART scores and the clinical outcome scores.

There are several limitations which we must acknowledge. As with any retrospective study, the lack of preoperative clinical outcome scores limits the ability to accurately identify improvement at postoperative follow-up. Additionally, the lack of a control or alternative treatment group makes direct comparisons with other treatments problematic. The sample size limits the ability to draw conclusions regarding correlations between MOCART scores and clinical outcome scores. No plain X-ray radiographic description of tibiofemoral or patellofemoral alignment is provided, however no patients were treated with concomitant osteotomies. Five patients underwent major concomitant procedures and five underwent moderate concomitant procedures. Obviously, the functional results and clinical scores for these patients may have been significantly

affected by these concomitant procedures. Patients 8 and 10 were the only two patients that did not have a concomitant procedure. Patient 8 is a young male who is very active in recreational and competitive sports and running; all of his PRO scores were higher than the mean scores. Patient 10 is an older female who does not participate in any activities besides walking; all of her PRO scores were lower than the mean scores. As with most cartilage studies, the patients studied had a heterogeneous mix of cartilage injuries, with only four patients having isolated, uni-compartmental defects. The others received chondroplasties or abrasion chondroplasties for their grade 2 and 3 lesions in the compartments that were not managed with CVOCA grafting. Procedural study strengths include a single surgeon at a single institution, a consistent surgical protocol, a consistent rehabilitation protocol and a blinded fellowship-trained musculoskeletal radiologist independently evaluating each MRI to determine the MOCART scores.

5. Conclusion

To the best of our knowledge, this is the largest series to report clinical and MRI outcomes in patients undergoing CVOCA implantation for the treatment of focal cartilage defects in the knee. The implant demonstrated no clinical or MRI failures and no complications at 2-year follow-up. The short term results were comparable to outcomes of fresh OCA. Longer-term clinical outcomes and cost analyses of the CVOCA in comparison to other cartilage grafting techniques remain to be determined. Controlled, randomized studies are suggested for evaluation of CVOCA efficacy, durability and long-term outcomes.

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Approval

This study was approved by the Institutional Review Board (IRB) Committee at the University of Maryland, Baltimore (HP-00066115).

Declaration of competing interest

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