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Articular cartilage paste graft for severe osteochondral lesions of the knee: a 10- to 23-year follow-up study

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Abstract
Purpose The purpose of this study is to evaluate the clinical outcomes of the articular cartilage paste graft procedure at a minimum of 10 years from surgery. It is hypothesized that articular cartilage paste grafting can provide patients with a durable repair of severe full-thickness osteochondral injuries, measured by persistence of procedure-induced benefit and subjective outcome scores at 10 or more years.
Methods Seventy-four patients undergoing paste grafting at a mean age of 45.3 ± 10.8 years (range 13–69 years) were followed up at a mean of 16.8 ± 2.4 years (range 10.6–23.2 years) post-operatively using validated subjective outcome measures; Kaplan–Meier survival analysis was performed to estimate expected population benefit time.
Results Kaplan–Meier estimated median benefit time of 19.1 years (mean: 16.6 ± 0.9 years) for all patients undergoing paste grafting. Thirty-one (41.9 %) patients had progressed to arthroplasty at a mean of 9.8 ± 5.6 years (range 0.4–20.6 years). Ninety percent of patients reported that the procedure provided good to excellent pain relief. Median IKDC subjective score increased significantly at most recent follow-up (70.1) compared to preoperative (55.7, $p = 0.013$). Median WOMAC scores decreased significantly from 26 to 14 ($p = 0.001$). Median Tegner score increase from 4 to 6 was not found to be significant (ns). VAS pain averaged 23/100 at most recent follow-up.
Conclusions Patients who underwent the paste grafting reported improved pain, function, and activity levels for an expected mean of 16.6 years, and for those who ultimately progressed to knee replacement, surgical treatment including the paste graft was able to delay arthroplasty until a mean age of 60.2 years, an age at which the procedure is commonly performed. Full-thickness articular cartilage loss can be successfully treated, reducing pain, and improving function, using this single-step, inexpensive arthroscopic procedure.
Level of evidence IV.

Keywords Articular cartilage · Knee · Osteoarthritis · Arthroscopy · Biologic knee repair · Autologous cartilage transplantation · Osteochondral grafting · Articular cartilage repair · Long-term clinical outcome · Survival analysis · Histology · Paste graft · Treatment gap · Orthobiologics · Cartilage reconstruction

Introduction

Biologic treatments for chronic, full-thickness articular cartilage lesions in the knee have the common goal of improving function of the injured joint, providing pain relief, and providing durable defect coverage. With a substantial increase in osteoarthritis (OA) prevalence projected over the next few decades [9], biologic procedures may be part of the solution to control the burgeoning economic burden of OA.

The articular cartilage paste graft was developed as a cost-effective, minimally invasive technique for cartilage repair indicated for both widespread and focal cartilage damage [38]. It is entirely arthroscopic, uses autologous tissue, and is performed in a single session requiring only

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readily available surgical equipment. The procedure aims to treat full-thickness cartilage defects by providing suitable biologic conditions for a healing response to occur. The technique, much like microfracture, uses lavage, debridement, and subchondral fracture to stimulate bone marrow-derived autologous cell proliferation, differentiation, and growth factor release [3, 12, 27, 45]. In order to provide three-dimensional autogenous cartilage matrix with chondrocytes to large defects, an osteochondral plug is harvested from the intercondylar notch, crushed into a paste, and impacted into the fractured chondral defect. The morselized paste of articular cartilage and subchondral bone is hypothesized to augment the mesenchymal stem cell supply from vascularized subchondral marrow access and may present the necessary cellular signals and conductive matrix to produce an appropriate repair tissue. Preclinical and clinical studies have further suggested the utility of paste grafting as compared to controls and shown regeneration of cartilage repair surfaces histologically in defects both in arthritic knees and acute traumatic injuries [17–20, 25, 37, 40, 45].

The purpose of this study is to evaluate the clinical outcomes of the articular cartilage paste graft procedure at a minimum of 10 years from surgery. It is hypothesized that articular cartilage paste grafting can provide patients with a durable repair of severe full-thickness osteochondral injuries, measured by persistence of procedure-induced benefit and subjective outcome scores at 10 or more years.

Materials and methods

A total of 354 consecutive patients (392 procedures) were treated with the articular cartilage paste graft procedure at our clinic. Prior to undergoing any treatment, patients were taken through an IRB-approved consent process to prospectively collect and store their data in a clinical outcomes database. The population for this report was retrospectively determined based on the following inclusion criteria: clinical presentation of full-thickness Outerbridge grade IV chondral defects [33] (with visual evidence of cartilage erosion to the subchondral bone or eburnation either during previous surgery, an MRI, radiograph or combination of MRI and radiograph), treatment of articular cartilage paste grafting at least 10 years prior to study initiation, participation in a defined post-operative rehabilitation program, absence of severe (<7°) malalignment in the coronal plane, a stable or stabilized joint, and exhaustion of non-operative care prior to undergoing paste grafting. Study exclusion criteria included the following: indication of inflammatory arthritis, isolated patellar lesions, and acute focal chondral defects.

A total of one hundred twenty patients met inclusion criteria and were contacted extensively for follow-up first by a maximum of three emails, followed by a letter, and lastly a series of up to three phone calls. One patient (0.8 %) was deceased, and 45 (37.5 %) were lost to follow-up. These 46 patients were removed from the study, leaving 74 (61.7 %) patients in the final study population. Twenty-eight (37.8 %) females and 46 (62.2 %) males received a paste graft procedure from January 1992 to July 2000. The average time from surgery to most recent follow-up was 16.8 ± 2.4 years (range 10.6–23.2 years).

Lesion size estimation

Prior to any treatment of lesions, a size estimate was taken under arthroscopic visualization, and estimated mean length and width measurements were recorded. A measurement of depth was recorded for defects extending past the tidemark. Measurements were taken with accuracy to 1 mm. Elliptical surface area in mm^2 was calculated as a conservative estimate of lesion size using major and minor axes with the equation:

$$\text{area} = \pi \times \frac{\text{length} \times \text{width}}{4}$$

Finally, lesions were stratified into three groups based on the length of the larger axis as small (<10-mm), medium (10–20-mm), or large (≥20-mm).

Surgical method

The articular cartilage paste graft uses autologous cartilage in a single-step, entirely outpatient procedure [38]. In short, the defect is first debrided and then completely morselized and a fresh fracture base created through to subchondral bone with extensive use of microfracture awls (Fig. 1a). Next, one to two 8 × 15-mm plugs of articular cartilage and underlying cancellous bone are harvested from the intercondylar notch using a trephine and impacted into a paste. The paste is impacted into the morselized chondral defect and held in place for up to 2 min or until blood clotting is observed (Fig. 1c). Meniscal transplantation was performed in patients with missing or irreparably damaged menisci at surgeon discretion, either at the time of paste grafting or in a second-staged procedure. All meniscus transplantations are performed using the three-tunnel technique [39].

Post-operative care

Patients were discharged from the outpatient surgery center on the day of surgery. All patients underwent a defined rehabilitation program regardless of treated lesion location(s) as reported previously [40]. In addition, patients used a continuous passive motion device for 4 weeks, 6 h per day. At 4 weeks, full weight-bearing exercises were permitted as

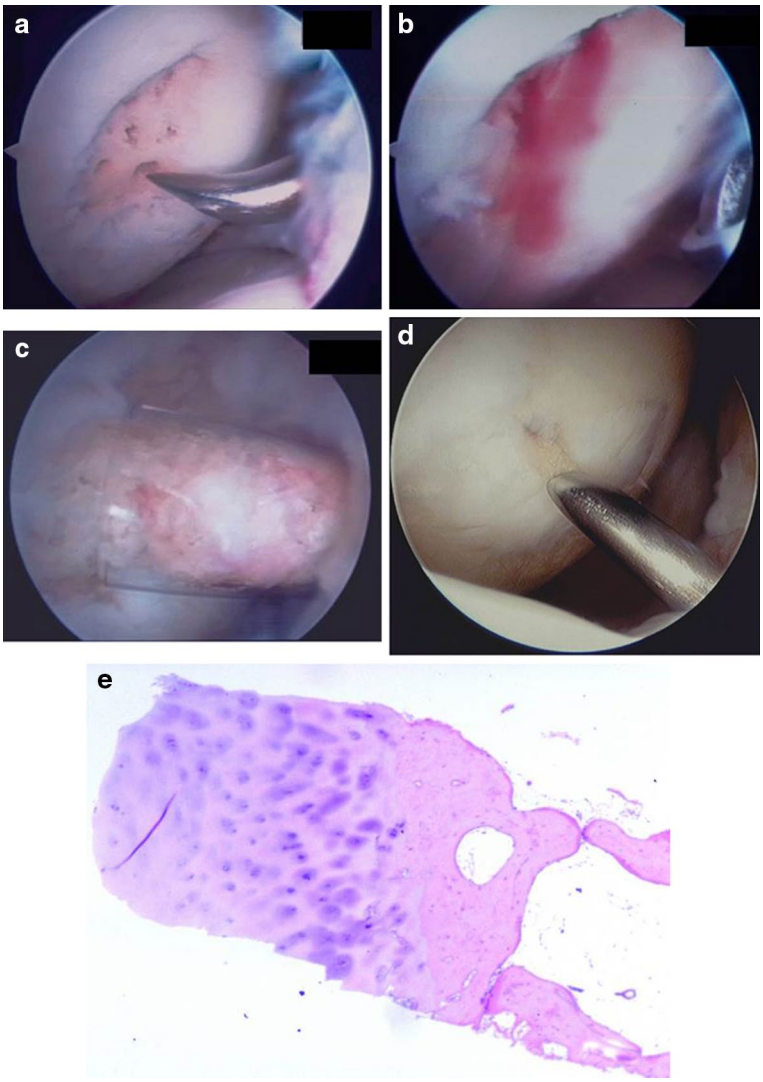

Fig. 1 Forty-eight-year-old male patient with articular cartilage damage on the medial femoral condyle. **a** The defect is cleared of all calcified and necrotic tissue, followed by morselization of the defect bed. **b** Bleeding from the marrow cavity, which is thought to deliver progenitor cells and growth factors, is confirmed. **c** The paste of articular cartilage and cancelous bone is impacted into the defect. **d** A biopsy is taken during a second-look arthroscopy at 7 months post-paste grafting. **e** An H&E stained section of the biopsy shows hyaline-like repair tissue with a clearly established tidemark

well as non-impact sports (swimming, cross-country skiing, weight lifting) for the following 5 months. Impact sports were allowed to commence after the sixth month.

Follow-up

Patients were asked to return to our clinic to undergo a second-look arthroscopy and biopsy of the repair tissue generated by the paste graft procedure. Repair tissue biopsies were collected with a 14-gauge Jamshidi needle (Fig. 1d), placed in 10 % NBF, embedded, sectioned, and stained with H&E, Safranin-O/Fast Green, or toluidine blue (Fig. 1e). An independent, blinded histologist graded the samples based on at least partial presence of the following seven characteristics: (i) *hyaline-like cartilage*, (ii) *fibrocartilage with glycosaminoglycan (GAG)*, (iii) *fibrocartilage without GAG*, (iv) *fibrous tissue*, (v) *repair tissue indistinguishable from native articular cartilage*, (vi) *intact repair surface*, and (vii) *presence of tidemark* [40].

Patients completed the following validated subjective outcome scores preoperatively and at follow-up: Western Ontario McMaster Osteoarthritis Index (WOMAC); International Knee Documentation Committee Subjective Knee Form (IKDC); and Tegner Activity Index [2, 16, 42]. Patients completed a Visual Analog Scale (VAS) for Pain and a Patient Satisfaction Questionnaire at latest follow-up. Biopsies were collected under protocol approved by CPMC IRB (97.035), and follow-up data were collected per protocol as approved by E&I IRB (10008).

Statistical analysis

Variables were tested for normal distribution by the Kolmogorov–Smirnov test. Continuous variables are presented as mean ± standard deviation (SD) and as median [interquartile range (IQR)]; categorical variables as number and percentage. The Kaplan–Meier (KM) product limit estimator was used to estimate the duration/persistence

of procedure-induced benefit experienced by the patient population, defined as the time from initial paste grafting to arthroplasty or alternative cartilage repair procedure, or when pain reported at follow-up is not improved from pain reported preoperatively. Results are presented as mean ± SD and 95 % confidence interval (CI). The effect of potential clinically confounding variables on duration of procedure-induced benefit was analysed using Cox's proportional hazards model. Potential hazards were examined for independent effect on benefit time, followed by backward stepwise regression analysis to arrive at a final model. Analysis of subjective clinical follow-up scores was carried out using the Mann–Whitney *U* test. Post hoc power estimates for comparison with pre- and post-operative IKDC, WOMAC, and Tegner scores were 0.811, 0.694, and 0.320 respectively. Data analysis was performed using R version 3.3.1 [35]. Significance was set at $\alpha < 0.05$ for all tests.

Results

Patient demographics

Patients underwent initial paste grafting at a mean age of 45.3 ± 10.8 years (range 13–69 years). The majority of the patients (52, 70.3 %) in the study population presented with chronic symptoms lasting for more than 1 year prior to undergoing the paste graft procedure. The average time from initial injury to surgery for the chronic patients was 10.7 ± 10.9 years (range 0–45.4 years) (Table 1).

Table 1 Duration and cause of preoperative symptoms

	n (%)
Duration of symptoms	
Less than 1 month	6 (8.1 %)
1–3 months	2 (2.7 %)
4–12 months	12 (16.2 %)
>1 year	54 (73.0 %)
Type of injury	
Sport	32 (43.2 %)
No known injury	26 (35.1 %)
Work accident	7 (9.5 %)
Fall	2 (2.7 %)
Motor vehicle accident	2 (2.7 %)
Other accident	5 (6.8 %)

Previous surgeries

Fifty-four patients had undergone a median of 2 (IQR: [1,2], range 1–13) surgeries prior to undergoing the paste graft procedure (Table 2).

Index surgery treatment

Patients had a median of 1 (IQR: [1,1], range 1–3) treatment site including grafting of lesions located on the medial femoral condyle (53, 71.6 %), trochlea (15, 20.3 %), lateral femoral condyle (14, 18.9 %), medial tibial plateau (7, 9.5 %), and lateral tibial plateau (3, 4.1 %). Prior to any treatment, the mean length estimation of the lesions was 18 ± 9 mm (range 6–40 mm). The mean width estimation of the lesions was 14 ± 8 mm (range 3–55 mm). The mean calculated elliptical area of the lesions was 212 ± 206 mm^2 (range 27–1296 mm^2). Lesions were categorized as small (20/92, 21.7 %), medium (44/92, 47.8 %), and large (28/92, 30.4 %).

Concomitant surgeries

A variety of concomitant surgical procedures were performed at the time of initial paste grafting to address comorbidities in the knee. Fifty-seven (77.0 %) patients required a median of 1 procedure (IQR: [1,2], range 1–4 procedures).

Additional surgical interventions

Thirty-three (44.6 %) patients required an average of 1.4 ± 0.7 non-arthroplasty surgeries (range 1–4 surgeries) following initial paste grafting.

Biopsies

Biopsies of the repair tissue generated from the paste graft were acquired from 29 (39.2 %) patients at a median of 14 months (IQR: [11,24], range 3–54 months). Fourteen (48.3 %) biopsies contained hyaline-like cartilage, 24 (82.8 %) contained fibrocartilage with GAG, 10 (34.5 %) contained fibrocartilage without GAG, and 3 (10.3 %) contained fibrous tissue. The repair tissue was indistinguishable from native articular cartilage in 4 (13.8 %) biopsies, had an intact repair surface in 24 (82.8 %) biopsies, and had an established tidemark in 5 (17.2 %) biopsies. Univariate analysis of the seven descriptive indices of cartilage repair biopsies failed to find any significant difference in benefit time at different levels of the indices. Therefore, regression analysis for cartilage indices was not performed.

Table 2 Previous, concomitant, and additional surgical procedures

	n (%)
Previous procedures	
Partial meniscectomy	32 (37.2 %)
Total meniscectomy	4 (4.7 %)
Other meniscus procedure	3 (3.5 %)
Microfracture	14 (16.3 %)
Other chondral repair procedure	11 (12.8 %)
ACL reconstruction	10 (11.6 %)
Other ligament procedure	6 (7.0 %)
Removal of loose bodies	3 (3.5 %)
Diagnostic arthroscopy	1 (1.2 %)
Tendon surgery	1 (1.2 %)
Other procedures	1 (1.2 %)
Concomitant procedures	
Partial meniscectomy	20 (20.6 %)
Meniscus allograft transplantation	19 (19.6 %)
Chondroplasty	17 (17.5 %)
Microfracture	17 (17.5 %)
Autograft ACL reconstruction	8 (8.2 %)
Osteotomy	7 (7.2 %)
Meniscus repair	6 (6.2 %)
Allograft ACL reconstruction	3 (3.1 %)
Additional procedures	
Paste grafting	
Same location	5 (6.8 %)
New location	3 (4.1 %)
Microfracture	
Same location	5 (6.8 %)
New location	4 (5.4 %)
Chondroplasty	
Same location	5 (6.8 %)
New location	3 (4.1 %)
Non-cartilage	
Partial meniscectomy	15 (20.3 %)
Staged meniscus allograft	8 (10.8 %)
Meniscus allograft repair	4 (5.4 %)
ACL reconstruction	1 (1.4 %)
Loose body removal	1 (1.4 %)
Osteophyte removal	2 (2.7 %)

Follow-up population

Mean age at latest follow-up was 59.8 ± 9.6 years (range 28.4–79.5 years). Thirty-one (41.9 %) had progressed to arthroplasty at a mean of 9.8 ± 5.6 years (range 0.4–20.6 years) and were an average of 60.3 ± 7.6 years old (range 44–79.5 years old).

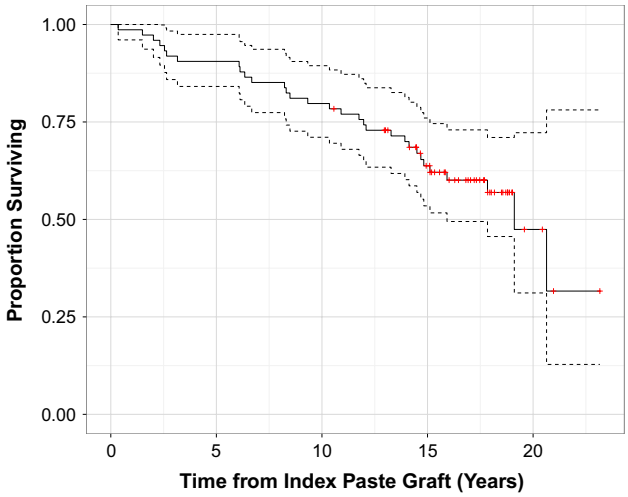

Fig. 2 Baseline Kaplan–Meier survival curve. The estimated mean benefit time is 16.6 ± 0.9 years (median: 19.1 years) for all patients undergoing paste grafting

Survival analysis

Kaplan–Meier (KM) analysis of the study population estimated a mean benefit time of 16.6 ± 0.9 years (median: 19.1 years) for all patients undergoing paste grafting (Fig. 2; Table 3) Univariate testing determined that the variables *ACL Injury*, *Age At Surgery*, *Biopsy Taken*, *Bipolar Lesions*, *Concomitant Meniscus Allograft*, *Number of Lesions*, *Number of Previous Surgeries*, and *Total Area Grafted* had an independent effect on proportional hazards. The final model contained the parameters *ACL Injury*, *Age At Surgery*, *Bipolar Lesions*, *Number of Previous Surgeries*, and *Total Area Grafted*.

Function

The median IKDC score at most recent follow-up of 70.1 (IQR: [50.6,86.2], range 25.3–97.7) was significantly higher than the preoperative median score of 55.7 (IQR: [39.4,62.1], range 14.5–74.7, $p = 0.013$) (Fig. 3). The median normative IKDC score at most recent follow-up was 0.6 (IQR: [−0.2,2.6], range −2.5 to 4.0). The median WOMAC score at most recent follow-up of 14 (IQR: [2,27], range 0–55) was significantly lower than the preoperative median score of 26 (IQR: [11,42], range 3–65, $p = 0.001$).

Activity level

The median Tegner score at most recent follow-up of 6 (IQR: [4,6], range 1–10) was not significantly higher than the preoperative median score of 4 (IQR: [3,6], range 1–9, $p = 0.119$).

Table 3 Hazards to estimated duration of surgical benefit

	Mean ± SD/*n* (%)	Final Exp (Coef)	Coef *p* value	Group benefit (yrs) Mean ± SD (median)	KM *p* value
ACL injury					(ns)
No	63 (85)	–	–		
Yes	11 (15)	7×10^{-9}	(ns)		
Age at surgery					0.005**
Under 40	23 (31)	–	–	19.8 ± 0.5[a]	
40–50	21 (28)	3.690	0.033*	16.3 ± 1.3 (19.1)	
50 plus	30 (41)	6.084	0.002**	13.1 ± 1.4 (13.1)	
Bipolar lesions					0.004**
No	53 (72)	–	–	18.0 ± 0.9 (19.1)	
Yes	21 (28)	2.246	(ns)	12.3 ± 1.7 (12.1)	
Previous surgeries					0.024*
Zero	20 (27)	–	–	18.4 ± 1.2[a]	
One	26 (35)	3.325	0.046*	16.0 ± 1.3 (20.6)	
Two plus	28 (38)	4.281	0.018*	14.1 ± 1.3 (15.1)	
Total area grafted (mm^2)	264 ± 269	1.001	(ns)		

Summary of variables examined in Cox's proportional hazards analysis

KM Kaplan–Meier, *yrs* years, *SD* standard deviation, *ns* non-significant

* $p < 0.05$; ** $p < 0.01$

[a] More than half of the patients had ongoing benefit at the end of the study, no median time calculated

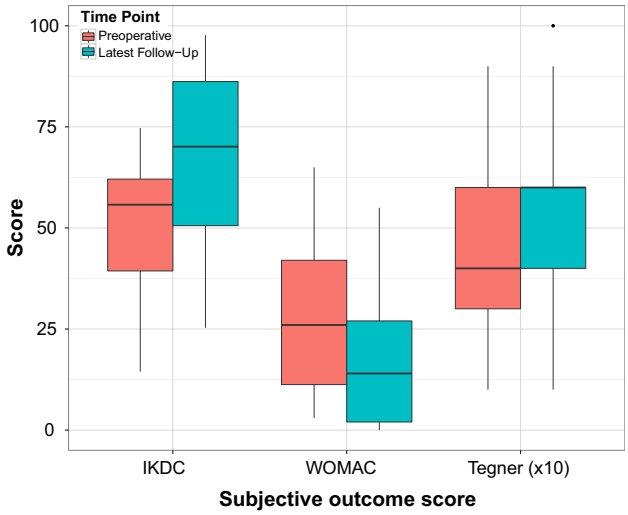

Fig. 3 IKDC, WOMAC, and Tegner Scores preoperatively and at most recent follow-up. The median IKDC score at most recent follow-up of 70.1 (IQR: [50.6,86.2], range 25.3–97.7) was significantly higher than the preoperative median score of 55.7 (IQR: [39.4,62.1], range 14.5–74.7, $p = 0.013$). The median WOMAC score at most recent follow-up of 14.0 (IQR: [2.0,27.0], range 0.0–55.0) was significantly lower than the preoperative median score of 26.0 (IQR: [11.2,42.0], range 3.0–65.0, $p = 0.001$). The median Tegner score at most recent follow-up of 6.0 (IQR: [4.0,6.0], range 1.0–10.0) was not significantly higher than the preoperative median score of 4.0 (IQR: [3.0,6.0], range 1.0–9.0, $p = 0.119$)

Pain and satisfaction

When rating how normal their affected joint felt on a scale of 0 to 100 (100 = most normal), patients reported a mean rating of 68 ± 29 (range 0–100). When rating medical care satisfaction on the same scale (100 = most satisfied), the mean satisfaction rating was 93 ± 13 (range 43–100). Rating pain on a scale of 0–100 (100 = worst pain), patients reported a mean pain rating of 23 ± 25 (range 0–87). Additionally, when asked how well the procedure relieved their pain, 90.2 % of patients reported *good* to *excellent*. When asked how well the procedure increased their ability to perform regular activities, 92.7 % of patients reported *good* to *excellent* results, and 80.5 % of patients reported *good* to *excellent* return to heavy work or sports (as allowed). When asked how well the procedure met their expectations, 90.2 % of patients reported *good* to *excellent* and 90.2 % of patients reported *probably yes* or *definitely yes* that they would undergo the procedure again if needed.

Discussion

The most important finding of the present study was that the paste graft procedure relieved pain and improved function

in patients at an average follow-up time of 16.8 years. This study aims to provide insight into the feasibility of the paste graft procedure in an age group where OA diagnoses are increasingly prevalent, but knee arthroplasty is not yet desired by the patient nor generally recommended [5, 9, 44]. Patients who underwent paste grafting at a minimum of 10 years prior to follow-up were selected for this study. On average they were 45 years old with arthritic pain, the age at which many patients are told to live with their knee, take drugs, reduce activities, and wait until they are older to receive arthroplasty as a definitive treatment. Statistical analysis on the duration of procedure-induced benefit from the paste graft and subjective outcome scores are reported from patients at a 10- to 23-year follow-up range.

With the expansion of the field of biologic repair in recent decades, there is an increasing need to study the extended long-term durability of techniques treating articular cartilage damage in the knee. Microfracture is currently the most widely used procedure to treat osteochondral defects. Microfracture touts some of the same benefits as the paste graft technique: being low cost, arthroscopic, outpatient, single-session, and requiring only readily available surgical equipment.

However, microfracture is not indicated for OA and is not considered a viable long-term solution for cartilage defects. Numerous studies have shown minimal cartilage regenerate and rapid functional decline as early as 2 years post-operation [14, 21, 22, 28, 36]. A study in a rabbit cartilage defect model demonstrated significantly superior defect fill, glycosaminoglycan staining, and collagen type II and aggrecan presence in the paste as compared to microfracture [45]. The study suggests that paste grafting can result in improved quality of the repair tissue and may have a positive effect on the integration with the surrounding cartilage.

Excellent graft persistence and patient-reported pain relief, function, and quality of life were published on the medium to long-term outcomes of the paste graft [40]. That case series study reported on 125 patients over 2–12 years, with significant improvements ($p < 0.001$) in validated subjective outcomes measuring pain, function, and activity and a 14.4 % failure rate. The current study expands on these results, suggesting that the significant improvements in pain and function seen in the 2- to 12-year period can be sustained 10–20 years from surgery.

Significant findings from the present clinical study include improved pain relief and function levels in patients 10–23 years after undergoing the paste graft procedure. Comparable published literature and normative data on other biologic repair techniques underscore the effectiveness of paste grafting in arthritic knees [4, 26, 34, 43, 46]. In comparison with microfracture in particular, this study suggests paste grafting can provide enhanced regenerate persistence and significant increases in patient function while reducing pain. Furthermore, given that the patient population in this study reported outcome scores at a higher average age and over a longer follow-up period compared to most key alternative studies, the paste graft may prove worthy of critical longevity comparison with other biologic procedures.

This is especially relevant given the increasing global prevalence of OA and the emergence of a treatment gap between time of exhaustion of conservative treatments and time of surgical intervention, in particular arthroplasty [9]. This gap is estimated to last at least 20 years and affect 5 million people in the USA by 2025 [24]. In 2010, the average age of patients undergoing knee replacement was reported as approximately 70 years [1, 31, 41]. Although there is no definitive age minimum for patients opting for knee arthroplasty, it has been shown that the risk of revision for arthroplasty is almost five times greater for patients younger than 55 compared to patients aged 75 years or older [6]. Not surprisingly, there is a strong surgeon consensus calling for improved methods to address the treatment gap for OA patients under 60 years old who are physically active and not yet recommended for knee replacement [23].

In this current study, patients were treated with the paste graft procedure at an average age commonly not indicated for arthroplasty. The 31 (41.9 %) patients who progressed to knee arthroplasty before study conclusion did so at an average age of 60.3 years and an average of 9.8 years following the paste graft. This demonstrates that paste grafting can be a clinically feasible solution for getting patients past the treatment gap until arthroplasty is appropriate. Furthermore, our hazard analysis revealed increased patient age as a factor affecting survivorship, suggesting an aggressive approach in the diagnosis and treatment of early osteoarthritic damage may be crucial in creating sustained relief for younger patients and maximizing benefit from the paste graft procedure.

Despite statistically significant hazards of bipolar lesions on duration of procedure-induced benefit from paste graft, it is important to note that the KM estimated mean time until arthroplasty or alternative biologic repair for patients with bipolar lesions (12.3 $\pm$ 1.7 years) was over 10 years. This augments previous findings that paste grafting can provide long-term benefits to patients with trochlear and bipolar lesions. Further studies with a greater number of patients beyond 10 years are necessary to confirm these preliminary findings.

There was no significant correlation found between outcome and any of the seven descriptive indices of cartilage repair biopsies. This suggests that defect coverage may be more critical than tissue type for extended long-term performance of cartilage repair (Fig. 4). This finding has merit

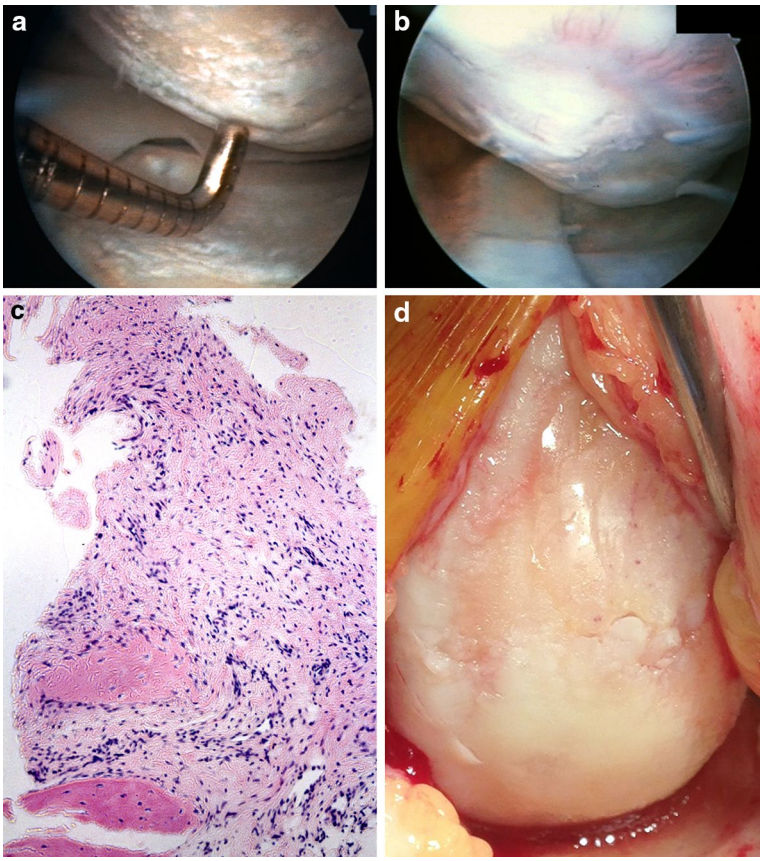

Fig. 4 Forty-two-year-old female patient with osteoarthritis of the medial femoral condyle. **a** Eburnated bone on the condyle prior to paste grafting. **b** Second-look arthroscopy 7 months post-paste grafting revealing highly vascularized juvenile cartilage on the edges and fibrous cover in the middle of the repair. **c** H&E stained biopsy taken during second-look arthroscopy showing highly cellular, disorganized repair tissue. **d** Intra-operative photo taken 20 years after paste grafting, prior to medial unicompartmental knee replacement showing intact repair tissue at the original site of paste grafting with eburnated bone through the rest of the compartment

considering cartilage grading of defect fill ≥67 % defect is viewed as nearly normal and an acceptable outcome in alternative technique mid to long-term studies [8, 13, 29, 30, 32].

Limitations

This study was not without limitations. These results could have been strengthened by controlling against a procedure such as microfracture. However, microfracture is not indicated for non-isolated chondral defects nor osteoarthritic knees, which was an inclusion criteria for this study [30]. Preceding the indexed surgery, 14 (18.9 %) in the study underwent the paste graft procedure after failed microfracture treatment and 2 (2.7 %) after failed OATS treatment. Short of a control group, subjective outcome scores provide a validated method of comparison with other published cartilage repair studies. Second, the 61.7 % response rate in this study could be seen as a potential source of bias. An extremely thorough follow-up protocol was followed, and patients were considered lost to follow-up only after exhausting all methods of contact. This present study was comparable to other retrospective orthopaedic studies with a similar follow-up time range [7, 10, 11, 15]. Finally, the paste grafts were performed by a single surgeon at a single site. While the inclusion of additional sites would have provided greater follow-up numbers and reduced bias, to the best of our knowledge, there were no other sites performing the paste graft with regularity during this study period.

Based on the results of this study, we believe full-thickness articular cartilage loss can be successfully treated, reducing pain, and improving function, using this single-step, inexpensive arthroscopic procedure.

Conclusions

In this study, patients who underwent the paste graft reported improved pain, function, and activity levels for an expected mean of 16.6 years, and for those who ultimately progressed to knee replacement, surgical treatment including the paste graft was able to delay arthroplasty until a mean age of 60.2 years, an age at which the procedure is commonly performed.

Compliance with Ethical Standards

Conflict of interest All authors declare no conflict of interest.

Funding There was no financial support used for this study.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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