



Contents lists available at ScienceDirect

Journal of Cartilage & Joint Preservation®

journal homepage: www.elsevier.com/locate/jcjp

Case Series

Articular cartilage paste grafting for post-traumatic ankle cartilage lesions: five-patient case series

Kevin R. Stone^{a,b}, Florene Xu^a, Miya Liku^a, Simaron Dhillon^a, Kalea Sheung^a and Mani Vessal^{a,*}^a Stone Research Foundation, San Francisco, CA, USA^b The Stone Clinic, San Francisco, CA, USA

ARTICLE INFO

Keywords:

Ankle
Arthritis
Cartilage
Osteoarthritis
Paste graft

ABSTRACT

Introduction: Post-traumatic ankle cartilage loss and early osteoarthritis often affect younger, active patients and may progress despite prior procedures, leaving limited joint-preserving options. We report early clinical outcomes of the articular cartilage paste graft technique adapted to the ankle.

Case presentation: Five patients with symptomatic full-thickness ankle cartilage loss/post-traumatic osteoarthritis involving the talus and/or distal tibia underwent single-stage ankle arthroscopy with debridement and marrow stimulation followed by implantation of autologous osteochondral paste harvested from the intercondylar notch of the knee. Outcomes were assessed at baseline, 6 months, 1 year, and 2 years using VAS pain at rest, during activity, and at night, and 2 supplemental mechanical symptom ratings (0-10): perceived stability and grinding. Mean pain during activity improved from 7.8 ± 1.79 at baseline to 2.4 ± 2.07 at 2 years ($\Delta 5.4 \pm 1.14$). Grinding improved from 7.4 ± 2.70 to 1.4 ± 1.67 ($\Delta 6.0 \pm 2.83$), and instability improved from 7.4 ± 1.82 to 3.2 ± 2.39 ($\Delta 4.2 \pm 3.27$). No patient underwent graft-related revision, arthrodesis, or total ankle arthroplasty.

Conclusion: The articular cartilage paste graft technique was feasible in the ankle and is associated with sustained improvements in pain and mechanical symptoms, leading to return to high-impact activities for most patients. These results support further evaluation of the paste graft as a viable treatment method that preserves the native joint and encourages full return to activity for patients with post-traumatic ankle cartilage loss.

Introduction

Osteoarthritis (OA) is a leading cause of disability, affecting approximately 595 million people globally.¹ Left untreated, OA contributes to joint degradation, pain, loss of function, and reduced quality of life.² Although knee and hip OA have received substantial attention, ankle OA remains less studied. Approximately 1% of the world's adult population is affected by ankle OA, which is often post-traumatic and presents in younger, active patients, extending the lifetime burden of disease.³

Current surgical options for ankle articular cartilage injury or OA include arthroscopic bone-marrow stimulation (microfracture), cartilage reconstruction procedures (osteochondral transplantation and cell-based repairs such as matrix-induced autologous

* Mani Vessal, Stone Research Foundation, 3727 Buchanan St, Suite 310, San Francisco, CA 94123.

Email address: mvessal@stoneresearch.org (M. Vessal).

<https://doi.org/10.1016/j.jcjp.2026.100325>

Received 20 February 2026; Revised 1 September 2026; Accepted 2 September 2026

Available online xxx

2667-2545/© 2026 The Authors. Published by Elsevier B.V. on behalf of International Cartilage Regeneration and Joint Preservation Society. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

chondrocyte implantation (MACI)), ankle arthrodesis, and total ankle arthroplasty. These operations can reduce pain and improve function, but durability and life-impact vary. Recent studies report survival rates of up to 10 years after treatment with microfracture, but when revision is required, it often occurs within the first several years after the index procedure.^{4,5} Reconstruction procedures can restore hyaline or hyaline-like surfaces but introduce donor-site morbidity (autograft), graft availability/failure risks (allograft), or 2-stage cost and graft issues (autologous chondrocyte implantation/MACI).⁶⁻⁹ At the end-stage, arthrodesis predictably relieves pain but sacrifices ankle motion and is associated with nonunion and progression of adjacent-joint degeneration.¹⁰ Total ankle arthroplasty preserves motion and improves gait but carries a risk of revision over 5 to 10 years.¹⁰⁻¹⁵ For active patients seeking to maintain mobility and quality of life, these limitations highlight the need for joint-preserving solutions with durable, cartilage-appropriate repair.

The articular cartilage paste graft was originally developed as a single-stage, minimally invasive, arthroscopic technique for treatment of articular cartilage lesions in the knee and aims to improve joint function, relieve pain, and provide durable defect coverage. It uses autologous tissue—an osteochondral plug harvested from the intercondylar notch of the knee—formed into a paste and impacted into the defect, providing a 3-dimensional cartilage-bone matrix that potentially augments mesenchymal stromal cell supply and offers structural and molecular cues for repair. Ex vivo characterization of the paste graft confirmed increased cell proliferation and expression of essential cartilage matrix components (collagen type I and type II, aggrecan, COMP) compared to an osteochondral plug without impaction.¹⁶ Clinically, knee patients reported improved pain, function, and activity levels when treated with paste grafting, resulting in a mean benefit time of 16.6 years and delay of arthroplasty until a mean age of 60.2 years.¹⁷

The biologic principles underlying paste grafting in the knee are directly translatable to the ankle. In the ankle, paste grafting combines aggressive marrow stimulation through morselization with implantation of a 3-dimensional autologous osteochondral paste into a prepared defect, capable of restoring a robust repair surface without sacrificing joint motion. Because the procedure can be completed in a single stage, uses standard arthroscopic equipment and autologous tissue, and preserves the native joint, it has the potential to delay or avoid more limiting options like arthrodesis or total ankle arthroplasty in select patients with ankle cartilage lesions.

Here, we report 5 cases of ankle arthritis with articular cartilage lesions treated with the articular cartilage paste graft. Each patient had previously been offered either ankle arthrodesis or possible ankle joint replacement and sought care to avoid those options. Dates of surgery ranged from 2021 to 2023, and patients were followed for 2 years with Visual Analog Scale (VAS) patient-reported measurements and a supplemental Pain Relief survey to capture mechanical symptoms. At 2-year follow-up, benefit from the treatment was preserved and sustained reductions in pain compared with baseline were reported by all patients. Taken together, these early findings highlight the clinical relevance of adapting a cartilage repair method developed for the knee to the ankle as an option for patients seeking to retain the native joint. The observed reductions in pain and mechanical symptoms, return to activity, and preservation of ankle motion support further evaluation of this approach.

Methods

Study design and patient selection

This was a retrospective case series of 5 consecutive adult patients who underwent ankle articular cartilage paste grafting at a single institution between 2021 and 2023. Inclusion criteria were: (1) symptomatic ankle pain attributed to full-thickness cartilage loss or post-traumatic OA confirmed on radiographs and/or MRI, (2) and failure of nonoperative treatment. Exclusion criteria were: (1) patients with an active infection, (2) or unwillingness to follow the post-operative rehabilitation program. A total of 24 patients have undergone treatment with paste grafting in the ankle at the reporting institution; however, only 5 were included in this study due to availability of patient-reported outcome measurements at baseline and at least 2 years postoperative. Additional clinical follow-up data available for 20 total patients, reported in [Tables S1-S3](#). Demographics, injury history, prior ankle procedures, lesion location, and imaging findings were abstracted from the medical record. Cases are presented as patients 1-5 ([Tables 1, 2, Tables S1-S3](#)).

This study was approved by the Institutional Review Board (Salus IRB No. 10008), and patients provided written informed consent for treatment and use of de-identified data for publication.

Table 1

Patient demographics and pre-operative history.

Patient ID	Age at surgery	Sex	Mechanism of injury	Time from injury to paste graft	Prior ankle procedures
1	36.75	Male	Car accident	11 y	External fixator placement; bone allograft of tibia and talus; hardware removal; Achilles tendon release
2	46.26	Male	Hang gliding	3 y	Open reduction internal fixation; hardware removal
3	37.43	Female	Skateboarding	19 y	ORIF; hardware removal
4	46.04	Male	Soccer	10 y	Microfracture; OCD excision
5	22.82	Male	Dirt biking	9 y	Ankle reconstruction; external fixation

Age, sex, injury mechanism, time from injury to surgery, and prior ankle procedures for the 5 patients treated with ankle articular cartilage paste grafting.

Abbreviations: OCD, osteochondritis dissecans; ORIF, open reduction and internal fixation.

Table 2
Intraoperative characteristics.

Patient ID	Laterality	Lesion site	Concomitant procedures
1	Right	Talus; distal tibia	Debridement
2	Left	Dorsal talus; distal tibia	Debridement, removal of osteophytes
3	Left	Dorsal talus; distal tibia	Debridement, chondroplasty, removal of osteophytes
4	Left	Dorsal talus	Debridement, removal of osteophytes
5	Left	Talus; distal tibia	Debridement, removal of osteophytes

Laterality, lesion location, and concomitant procedures performed at the index ankle arthroscopy and paste grafting.

Surgical technique

Osteochondral paste grafting was performed arthroscopically using a technique adapted to the ankle and based on the articular cartilage repair method previously described by our group.¹⁸ Standard anteromedial and anterolateral ankle portals were established, and diagnostic arthroscopy was performed. Any hardware, loose bodies, and unstable fibrocartilage or degenerative tissue from prior repair operations were removed. As integral components of the paste graft technique, the defect bed was debrided to expose a firm subchondral base, followed by marrow stimulation through morselization of the exposed bone with an arthroscopic pick until punctate bleeding was observed. These steps created a biologically active healing bed for graft incorporation.

Autologous tissue was then harvested from the ipsilateral knee through anteromedial and anterolateral portals. An 8-mm trephine was used to harvest 8-mm x 15-mm osteochondral plugs from the medial wall of the intercondylar notch. Two to 3 plugs (depending on defect size) were processed with a graft impactor (Richards/Smith & Nephew) into a paste, yielding approximately 2.2 to 3.0 mL from each plug of material. The paste was impacted into the prepared ankle defect(s) until flush with the surrounding articular surface. No effort was made to completely fill the defect because repair tissue may hypertrophy during healing. The graft was allowed to stabilize for 1 to 2 minutes prior to final inspection and closure.

Rehabilitation

Patients were non-weight bearing for 4 weeks and used a continuous passive motion device for 4 to 6 hours daily. Full weight bearing was introduced at 5 to 6 weeks with early cycling and pool-based exercise. Non-impact exercise began after 3 months, and only low-impact activity was allowed for 9 to 12 months.

Outcome measurements

Patient-reported outcomes were collected at baseline (BL), 6 months (6M), 1 year (1Y), and 2 years (2Y). Patients completed the VAS (0 = no pain, 10 = worst imaginable pain) to assess pain at rest, during activity, and at night.¹⁹

Patients also completed a supplemental Pain Relief survey to capture mechanical symptoms: perceived ankle stability (0 = completely stable, 10 = extremely unstable) and ankle grinding (0 = no grinding, 10 = severe grinding). Lower scores indicate better status. These questions are non-validated exploratory measures used to supplement pain ratings.

Primary and secondary outcomes

For this analysis, the primary outcome was the change in patient-reported ankle pain from baseline to 2-year postoperative follow-up timepoint, assessed using VAS scores and Pain Relief survey. Secondary outcomes were clinical status during follow-up, including change in ambulatory status, return to higher-demand activities, and the occurrence of graft-related revision surgery, ankle arthrodesis, or total ankle arthroplasty through 2 years.

Statistical analysis

Because of the small sample size ($n = 5$), only descriptive statistics were reported (mean, median, SD, and range) at each timepoint for each domain. Change scores (BL-2Y) were also summarized. No hypothesis testing was performed.

Results

Patient characteristics

Five patients (patient ID 1-5) underwent ankle articular cartilage paste grafting between 2021 and 2023. All had at least one prior ankle surgery with persistent pain and stiffness. Mechanisms of injury included high-energy trauma and sports injuries (Table 1). MRI demonstrated significant cartilage damage and post-traumatic OA features (Fig. 1). Multiple patients had been advised to undergo arthrodesis or were considered too young for total ankle arthroplasty. At baseline, most patients reported major activity limitations, including reliance on a cane or wheelchair or avoidance of outdoor walking.

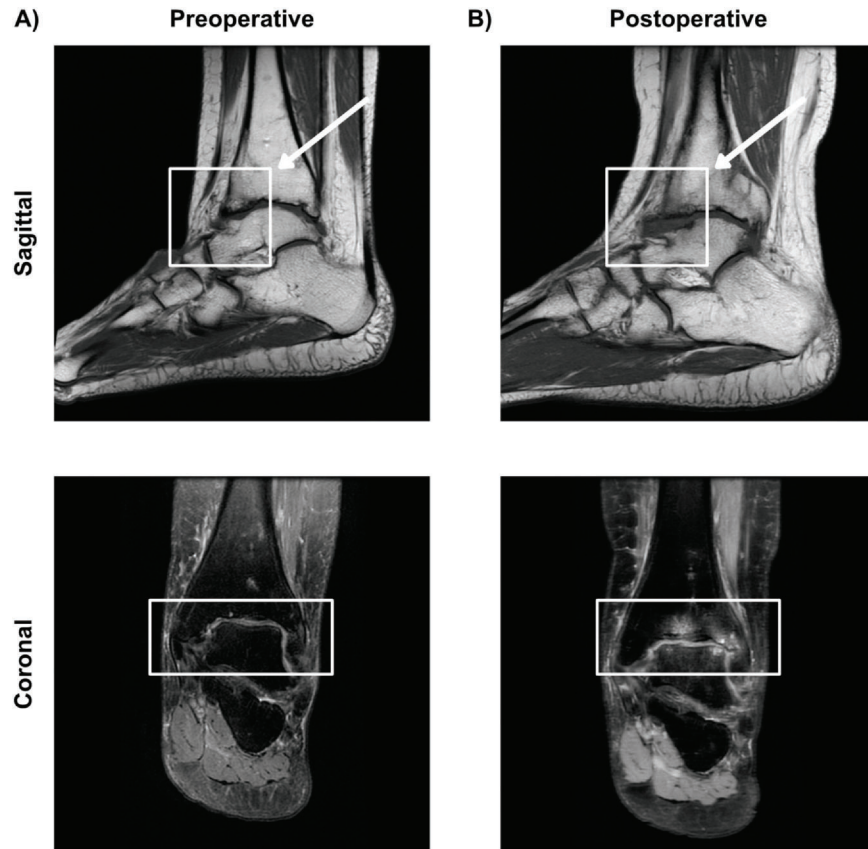


Fig. 1. Representative preoperative and postoperative ankle MRI following articular cartilage paste grafting. **A**, Preoperative sagittal T1-weighted and coronal proton-density images demonstrating anterior impingement and diffuse degenerative changes involving the talar dome and distal tibia. **B**, Postoperative MRI at approximately 12 mo demonstrating resolution of anterior impingement and maintenance of the tibiotalar joint space. Preservation of ankle motion was confirmed clinically, despite subchondral bone marrow edema. Boxes indicate the treated tibiotalar region.

Pain outcomes (VAS)

Activity pain was the most symptomatic domain at baseline (mean 7.8 ± 1.79 ; median 8.0; range 6-10) and decreased to 2.4 ± 2.07 at 2 years (median 2.0; range 1-6), corresponding to a mean change (Δ VAS activity) of 5.4 ± 1.14 points (median 5.0; range 4-7) (Table 3; Fig. 2B). Pain at night improved from 2.2 ± 1.64 (median 2.0; range 1-5) to 0.4 ± 0.89 (median 0; range 0-2) at 2 years (Δ VAS night 1.8 ± 1.92 ; median 1.0; range 0-5) (Table 3; Fig. 2C). Pain at rest was low at baseline (1.4 ± 0.55 ; median 1.0; range 1-2)

Table 3

VAS pain scores over time.

(A)			
Timepoint	At rest	During activity	At night
BL	1.4 ± 0.55	7.8 ± 1.79	2.2 ± 1.64
6M	0.25 ± 0.50	3.25 ± 1.89	0.25 ± 1.79
1Y	0.2 ± 0.48	2.5 ± 1.30	0.2 ± 1.79
2Y	1 ± 1.73	2.4 ± 2.07	0.4 ± 1.79
(B)			
Patient ID	Δ VAS rest	Δ VAS activity	Δ VAS night
1	0	7	5
2	-2	4	0
3	2	5	2
4	1	5	1
5	1	6	1
Mean change $\pm$ SD	5	5.4 ± 1.14	1.8 ± 1.92

(A) Visual Analog Scale (VAS) pain (0-10) at rest, during activity, and at night at baseline (BL), 6 months (6M), 1 year (1Y), and 2 years (2Y), reported as mean $\pm$ SD. (B) Individual BL-2Y change scores are shown. Lower scores indicate less pain. A positive Δ VAS indicates a decrease in pain score from BL to 2Y; a negative value indicates an increase.

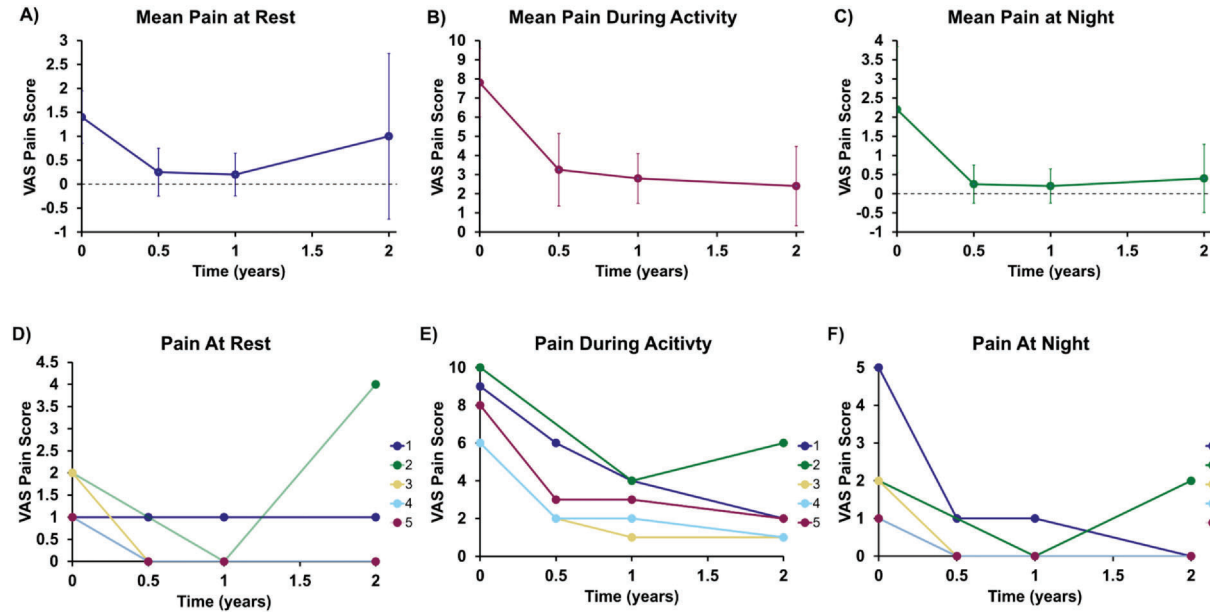


Fig. 2. Mean Visual Analog Scale (VAS) pain scores over time. Mean ($\pm$ SD) VAS pain scores (A) at rest, (B) during activity, and (C) at night at BL, 6M, 1Y, and 2Y after surgery. Individual patient (patient ID 1-5) trajectories (D) at rest, (E) during activity, and (F) at night.

and remained generally low at 2 years (1.0 ± 1.73 ; median 0; range 0-4) (Δ VAS rest 0.4 ± 1.52 ; median 1.0; range -2 to 2) (Table 3; Fig. 2A). Looking at individual patient VAS trajectories, all patients had equivalent or decreased pain scores in all categories from baseline to 2-year except Patient 2 (Fig. 2D and E), who had an increased pain at rest score from 2 to 4. Feedback from the patient clarified that this rating was an average of their experience as they had no pain in day-to-day life but require 1 to 2 days to recover from pain after prolonged periods of intense activity (running, dancing, sport, etc).

Perceived stability and grinding

Baseline perceived instability was high (mean 7.4 ± 1.82 ; median 7.0; range 5-10) and improved to 3.2 ± 2.39 at 2 years (median 2.0; range 1-7), with a mean change (Δ Stability) of 4.2 ± 3.27 points (median 3.0; range 0-8) (Table 4; Fig. 3A). Grinding decreased from 7.4 ± 2.70 at baseline (median 8.0; range 3-10) to 1.4 ± 1.67 at 2 years (median 1.0; range 0-4), with a mean change (Δ Grinding) of 6.0 ± 2.83 points (median 7.0; range 3-9). All patients reported reduced grinding (Table 4; Fig. 3B).

Table 4
Stability and grinding scores over time.

(A)		
Timepoint	Stability	Grinding
BL	7.4 ± 1.82	7.4 ± 2.70
6M	4.75 ± 2.62	1.25 ± 2.50
1Y	2.8 ± 1.30	1.4 ± 1.14
2Y	3.2 ± 2.39	1.4 ± 1.67
(B)		
Patient ID	Δ Stability	Δ Grinding
1	7	9
2	8	8
3	0	7
4	3	3
5	3	3
Mean change $\pm$ SD	4.2 ± 3.27	6 ± 2.83

(A) Numeric rating scores (0-10) for perceived ankle stability (0 = completely stable; 10 = extremely unstable) and grinding (0 = none; 10 = severe) at BL, 6M, 1Y, and 2Y, reported as mean $\pm$ SD. (B) Individual BL-2Y change scores are shown. Lower scores indicate improvement. A positive Δ indicates a decrease in stability or grinding score from BL to 2Y; a negative value indicates an increase.

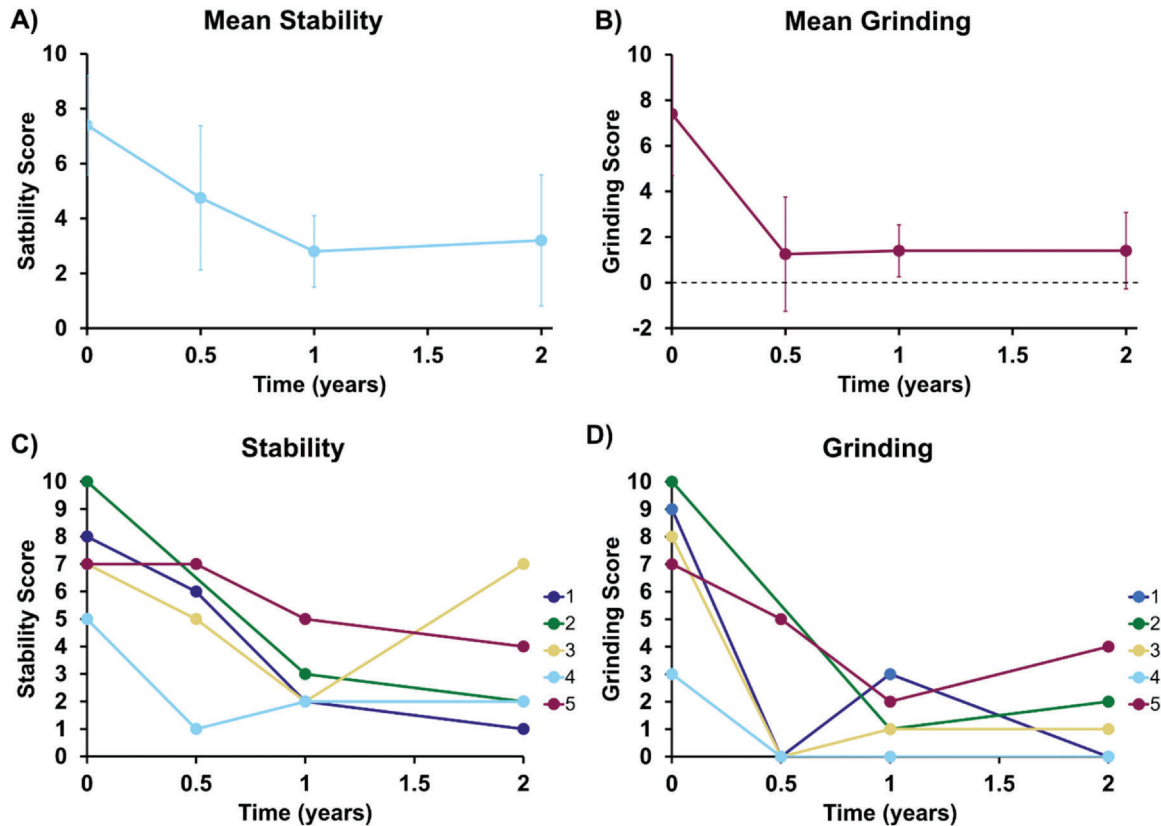


Fig. 3. Mean perceived ankle stability and grinding over time. **A,** Mean ($\pm$ SD) perceived ankle stability scores (0 = completely stable; 10 = extremely unstable) at BL, 6M, 1Y, and 2Y. **B,** Mean ($\pm$ SD) perceived ankle grinding scores (0 = none; 10 = severe) at BL, 6M, 1Y, and 2Y. Individual patient (patient ID 1-5) trajectories for **(C)** stability and **(D)** grinding.

Follow-up and outcomes

Follow-up examinations were consistent with the quantitative improvements. Four out of 5 patients progressed from limited mobility, including need for a cane or wheelchair in one case, to independent ambulation and returned to higher-demand activities (including running, hiking, and high-impact sports, and tactical fitness requirements) with residual stiffness in some cases. One patient underwent isolated debridement/osteophyte removal for mechanical impingement while the paste graft was left in situ. Importantly, no patient underwent ankle arthrodesis or total ankle arthroplasty during the 2-year follow-up, and no deep infections or graft-related revision procedures were identified. Clinical review of 20 treated patients, including some more than 15 years postoperatively, showed the same absence of conversion to arthrodesis or total ankle arthroplasty and graft-related revision (Tables S1-S3).

Discussion

This case series supports articular cartilage paste grafting adapted to the ankle and provides preliminary evidence of short-term clinical improvement for joint preservation in carefully selected patients with post-traumatic ankle cartilage loss or early OA who are otherwise facing arthrodesis or total ankle arthroplasty. Across 5 ankles, we observed improvements in activity-related pain and patient-perceived mechanical symptoms, with 4 patients returning to higher-demand and high-impact activities despite severe preoperative disease.

Within the broader treatment landscape, microfracture remains a common first-line procedure for small osteochondral lesions in the ankle because it is single-stage, low cost, and minimally invasive. However, repair tissue is predominantly fibrocartilage, and durability is variable, particularly in larger lesions.^{5,20} Furthermore, even in cohorts where the average survival rate is 10 years, revision procedures are common and occur within the first 2 to 3 years.^{4,5} When cartilage repair fails in progressive post-traumatic disease, patients may ultimately proceed to arthrodesis or total ankle arthroplasty, which can limit motion, function, and quality of life in patients with high-demand lifestyles.¹⁰⁻¹²

Examining cartilage repair procedures (microfracture, MACI, osteochondral autograft transfer system (OATS)) performed in the knee can provide a useful framework for translation into the ankle. Treatment of osteochondral lesions in the knee with microfracture

demonstrates good early symptom relief, but comparative long-term data suggests earlier and more frequent failure than osteochondral transplantation (OATS) in some cohorts (~4 years vs ~8.4 years).^{21,22} Additionally, microfracture is only beneficial for small lesions up to approximately 1.5 cm² with limited ability to address substantial bony involvement.²³ OATS and MACI can be used for larger lesions of 4 to 6 cm², with MACI having a mean benefit time of ~9.5 years and requiring a multi-stage procedure.^{22,23} Furthermore, microfracture is indicated only for isolated chondral defects in biomechanically aligned joints.^{24,25} In contrast, articular cartilage paste grafting in the knee is indicated in the setting of arthritis, and offers a single-stage, minimally invasive approach capable of addressing larger osteochondral defects (up to ~12.96 cm²) with bony involvement and a mean benefit time of 16.6 years.^{16,24} Given these metrics, it is clear there is a need for a more durable, joint-preserving option for treating ankle cartilage lesions. The favorable long-term outcomes, broader indications, and larger defect capacity of knee paste grafting provide a strong rationale for translating this approach to the ankle. However, these findings cannot be directly extrapolated to establish the long-term durability of paste grafting in the ankle or its superiority over established ankle cartilage restoration procedures.

While long-term durability of the paste graft in the ankle needs further analysis, it is promising that in this 2-year ankle series, no patient required graft-related revision surgery or progressed to arthrodesis or total ankle arthroplasty. Furthermore, adaptation of the paste graft from the knee to the ankle is technically feasible as no significant modifications are necessary. Additionally, the paste graft is capable of treating completely barren joints on both the tibia and talus, thus we have not yet encountered a limit on amount of cartilage loss or bone exposed. In a cohort with severe post-traumatic presentation and limited alternatives, these findings support the feasibility of the procedure and short-term improvements in pain, mechanical symptoms, and activity.

Clinically, this approach may be relevant for younger, active patients with extensive post-traumatic cartilage loss who wish to preserve ankle motion and avoid or delay arthrodesis or total ankle arthroplasty. The observed recovery of ambulation, return to higher-demand activities, and reductions in pain and mechanical symptoms support further evaluation of paste grafting in this patient population. Larger prospective and comparative studies are needed to determine whether these outcomes are sustained, and how paste grafting compares with established cartilage restoration procedures.

Four of 5 patients in this series underwent osteophyte removal as part of the index procedure. Recent in vitro work using human knee tissue suggests that osteophyte-derived cartilage may retain chondrogenic potential, with increased chondrocyte proliferation and expression of key genes for developing articular cartilage.²⁶ This raises the possibility that cartilage removed from ankle osteophytes could serve as an alternative autologous tissue source for paste graft preparation, reducing or eliminating the need for osteochondral tissue to be harvested from the knee. Further ex vivo and in vivo studies are needed before this tissue can be considered for clinical use in the ankle.

This study has some limitations. It is a retrospective series of 5 patients without a control group. Outcomes were restricted to numeric rating scales, and validated ankle-specific functional and quality-of-life patient-reported outcomes measures (PROMs) were not collected.

Donor-site morbidity is an important consideration when harvesting autologous osteochondral tissue from the knee. The intercondylar notch was used because it is arthroscopically accessible and provides viable autologous cartilage and osteochondral tissue for repair, with prior biomechanical work identifying nonloadbearing regions within the notch.^{16,27–30} Because donor-site morbidity was not assessed using knee-specific PROMs, formal range-of-motion measurements, or donor-site imaging, future prospective studies should include dedicated donor-site assessment.

Imaging follow-up was qualitative. Without second-look arthroscopy, quantitative imaging assessment, or histology, post-operative MRI findings should be interpreted cautiously and not considered definitive evidence of cartilage repair. Follow-up in this specific group was limited to 2 years, which may not capture late failures, though none have been reported in the larger cohort of patients to date. Baseline heterogeneity and concomitant procedures, such as osteophyte removal, also limit causal attribution to the paste graft alone.

Conclusion

In this case series, articular cartilage paste grafting for complex post-traumatic ankle cartilage loss was technically feasible and associated with sustained improvements in activity-related pain, mechanical symptoms, and return to high-impact function without progression to revision surgery, arthrodesis, or total ankle arthroplasty. Ongoing work aims to improve biologic repair and durability, building on promising preclinical studies of an augmented approach in the knee involving the addition of a hydrogel and allogeneic mesenchymal stromal cells to the paste graft. Future prospective clinical studies with larger cohorts, standardized imaging, and validated PROMs will be required to define indications and long-term survivorship in the ankle.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval

Complete written informed consent was obtained from the patient for the publication of this study and accompanying images. This study was approved by the Institutional Review Board (Salus IRB No. 10008), and patients provided written informed consent for treatment and use of de-identified data for publication.

Authorship contributions

K.R.S.: conceptualization, resources, supervision, visualization, writing – review & editing; F.X.: conceptualization, data curation, formal analysis, methodology, project administration, visualization, validation, writing – original draft, writing – review & editing; M.L.: conceptualization, data curation, methodology, project administration, validation; S.D.: conceptualization, supervision, validation, writing – review & editing; K.S.: writing – review & editing; M.V.: conceptualization, resources, supervision, validation, writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank Suneet Randhawa and Anderson Tran for their help in performing data gathering and organization.

Appendix A. Supplementary material

Supplementary material associated with this article can be found in the online version at [doi:10.1016/j.jcjp.2026.100325](https://doi.org/10.1016/j.jcjp.2026.100325).

References

- Steinmetz JD, Culbreth GT, Haile LM, et al. Global, regional, and national burden of osteoarthritis, 1990–2020 and projections to 2050: a systematic analysis for the global burden of disease study 2021. *Lancet Rheumatol*. 2023;5(9):508–522. [https://doi.org/10.1016/s2665-9913\(23\)00163-7](https://doi.org/10.1016/s2665-9913(23)00163-7)
- Hawker GA, King LK. The burden of osteoarthritis in older adults. *Clin Geriatr Med*. 2022;38(2):181–192. <https://doi.org/10.1016/j.cger.2021.11.005>
- Barg A, Pagenstert GI, Hügler T, et al. Ankle osteoarthritis: etiology, diagnostics, and classification. *Foot Ankle Clin*. 2013;18(3):411–426. <https://doi.org/10.1016/j.fcl.2013.06.001>
- Corr D, Raikin J, O’Neil J, Raikin S. Long-term outcomes of microfracture for treatment of osteochondral lesions of the talus. *Foot Ankle Int*. 2021;42(7):833–840. <https://doi.org/10.1177/1071100721995427>
- Rikken QGH, Aalders MB, Dahmen J, Sierevelt IN, Stufkens SAS, Kerkhoffs GMMJ. Ten-year survival rate of 82% in 262 cases of arthroscopic bone marrow stimulation for osteochondral lesions of the talus. *J Bone Jt Surg Am*. 2024;106(14):1268–1276. <https://doi.org/10.2106/JBJS.23.01186>
- Shimozono Y, Hurley ET, Myerson CL, Kennedy JG. Good clinical and functional outcomes at mid-term following autologous osteochondral transplantation for osteochondral lesions of the talus. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(10):3055–3062. <https://doi.org/10.1007/s00167-018-4917-3>
- Pereira GF, Steele JR, Fletcher AN, Clement RD, Arasa MA, Adams SB. Fresh osteochondral allograft transplantation for osteochondral lesions of the talus: a systematic review. *J Foot Ankle Surg*. 2021;60(3):585–591. <https://doi.org/10.1053/j.jfas.2021.02.001>
- Juels CA, So E, Seidenstricker C, Holmes J, Scott RT. A comparison of outcomes of revision surgical options for the treatment of failed bulk talar allograft transfer: a systematic review. *J Foot Ankle Surg*. 2020;59(6):1265–1271. <https://doi.org/10.1053/j.jfas.2020.07.005>
- Hu M, Li X, Xu X. Efficacy and safety of autologous chondrocyte implantation for osteochondral defects of the talus: a systematic review and meta-analysis. *Arch Orthop Trauma Surg*. 2023;143(1):71–79. <https://doi.org/10.1007/s00402-021-03990-1>
- Goldberg AJ, Chowdhury K, Bordea E, et al. Total ankle replacement versus arthrodesis for end-stage ankle osteoarthritis: a randomized controlled trial. *Ann Intern Med*. 2022;175(12):1648–1657. <https://doi.org/10.7326/M22-2058>
- Sanders AE, Kraszewski AP, Ellis SJ, et al. Differences in gait and stair ascent after total ankle arthroplasty and ankle arthrodesis. *Foot Ankle Int*. 2021;42(3):347–355. <https://doi.org/10.1177/1071100720965144>
- Deleu PA, Besse JL, Naaim A, et al. Change in gait biomechanics after total ankle replacement and ankle arthrodesis: a systematic review and meta-analysis. *Clin Biomech*. 2020;73:213–225. <https://doi.org/10.1016/j.clinbiomech.2020.01.015>
- Liu S, Wang Y, Zhang M, et al. A comparative study of modern total ankle replacement and ankle arthrodesis for ankle osteoarthritis at different follow-up times: a systematic review and meta-analysis. *Int Orthop*. 2023;47(6):1493–1510. <https://doi.org/10.1007/s00264-023-05753-6>
- Perry TA, Silman A, Culliford D, et al. Survival of primary ankle replacements: data from global joint registries. *J Foot Ankle Res*. 2022;15(1):33. <https://doi.org/10.1186/s13047-022-00539-2>
- Mok TN, He Q, Panneerselavam S, et al. Open versus arthroscopic ankle arthrodesis: a systematic review and meta-analysis. *J Orthop Surg Res*. 2020;15(1):187. <https://doi.org/10.1186/s13018-020-01708-4>
- Grande D, Goldstein T, Turek TJ, et al. Osteochondral autograft plugs versus paste graft: ex vivo morselization increases chondral matrix production. *Cartilage*. 2021;13(1 suppl):1058S–1065S. <https://doi.org/10.1177/1947603520916552>
- Stone KR, Pelsis JR, Na K, Walgenbach AW, Turek TJ. Articular cartilage paste graft for severe osteochondral lesions of the knee: a 10- to 23-year follow-up study. *Knee Surg Sports Traumatol Arthrosc*. 2016;25(12):3824–3833. <https://doi.org/10.1007/s00167-016-4323-7>
- Stone KR, Walgenbach AW. Surgical technique for articular cartilage transplantation to full thickness cartilage defects in the knee joint. *Oper Tech Orthop*. 1997;7:305–311.
- Sindhu BS, Shechtman O, Tuckey L. Validity, reliability, and responsiveness of a digital version of the visual analog scale. *J Hand Ther*. 2011;24(4):356–364. <https://doi.org/10.1016/j.jht.2011.06.003>
- Murawski CD, Foo LF, Kennedy JG. A review of arthroscopic bone marrow stimulation techniques of the talus: the good, the bad, and the causes for concern. *Cartilage*. 2010;1(2):137–144. <https://doi.org/10.1177/1947603510364403>
- Orth P, Gao L, Madry H. Microfracture for cartilage repair in the knee: a systematic review of the contemporary literature. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(3):670–706. <https://doi.org/10.1007/s00167-019-05359-9>
- Solheim E, Hegna J, Inderhaug E. Long-term survival after microfracture and mosaicplasty for knee articular cartilage repair: a comparative study between two treatments cohorts. *Cartilage*. 2020;11(1):71–76. <https://doi.org/10.1177/1947603518783482>
- Weishorn J, Wiegand J, Zietzschmann S, et al. Factors influencing long-term outcomes after matrix-induced autologous chondrocyte implantation: long-term results at 10 years. *Am J Sports Med*. 2024;52(11):2782–2791. <https://doi.org/10.1177/03635465241270152>
- Mithoefer K, Williams 3rd RJ, Warren RF, et al. The microfracture technique for the treatment of articular cartilage lesions in the knee. A prospective cohort study. *J Bone Jt Surg Am*. 2005;87(9):1911–1920. <https://doi.org/10.2106/JBJS.D.02846>
- Steinwachs MR, Guggi T, Kreuz PC. Marrow stimulation techniques. *Injury*. 2008;39(suppl 1):S26–S31. <https://doi.org/10.1016/j.injury.2008.01.042>

26. Kawabata S, Nakasa T, Nekomoto A, Yimati D, Miyaki S, Adachi N. Osteophyte cartilage as a potential source for minced cartilage implantation: a novel approach for articular cartilage repair in osteoarthritis. *Int J Mol Sci.* 2024;25(10):5563. <https://doi.org/10.3390/ijms25105563>
27. Niemeyer P, Pestka JM, Kreuz PC, et al. Standardized cartilage biopsies from the intercondylar notch for autologous chondrocyte implantation (ACI). *Knee Surg Sports Traumatol Arthrosc.* 2010;18(8):1122–1127. <https://doi.org/10.1007/s00167-009-1033-4>
28. Simonian PT, Sussmann PS, Wickiewicz TL, Paletta GA, Warren RF. Contact pressures at osteochondral donor sites in the knee. *Am J Sports Med.* 1998;26(4):491–494. <https://doi.org/10.1177/03635465980260040201>
29. Aurich M, Hofmann GO, Rolauffs B. Tissue engineering-relevant characteristics of ex vivo and monolayer-expanded chondrocytes from the notch versus trochlea of human knee joints. *Int Orthop.* 2017;41(11):2327–2335. <https://doi.org/10.1007/s00264-017-3615-y>
30. Ahmad CS, Cohen ZA, Levine WN, Ateshian GA, Mow VC. Biomechanical and topographic considerations for autologous osteochondral grafting in the knee. *Am J Sports Med.* 2001;29(2):201–206. <https://doi.org/10.1177/03635465010290021401>