

Assessment of Safe Cartilage Harvesting Quantity in the Shoulder: A Cadaveric Study



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Purpose: To evaluate the volume and yield of morselized cartilage that can be harvested from the shoulder for immediate reimplantation and repair. **Methods:** A standard arthroscopic approach was used to harvest non-load-bearing cartilage from 5 cadaveric shoulder specimens. Cartilage was separated from the humerus, grasped, added to the cartilage particulator, and morselized to form a cartilage paste. The volume of reclaimed cartilage was measured and compared with average humeral and glenoid defects. **Results:** The total yield of cartilage paste following tissue processing that was obtained from the 5 glenohumeral joints ranged from 1.0 mL to 2.4 mL with a mean volume of 1.9 ± 0.5 mL, yielding a theoretical $18.6 \text{ cm}^2 \pm 5.2 \text{ cm}^2$ of coverage with a 1-mm monolayer. Previously reported mean glenoid defect size ranges from 1.12 cm^2 to 2.73 cm^2 , while the mean humeral defect size ranges from 4.22 cm^2 to 6.00 cm^2 . **Conclusions:** This study validated that through a single-stage surgical and processing technique it is possible to obtain a sufficient volume for re-implantable autologous morselized cartilage graft to address most glenohumeral articular cartilage defects. **Clinical Relevance:** Chondrocyte grafts have been shown to be effective in cartilage repair. A single-site, single-staged procedure that uses a patient's autologous shoulder cartilage from the same joint has the potential to reduce morbidity associated with multiple surgical sites, multistaged procedures, or nonautologous tissue in shoulder surgery.

Articular cartilage defects of the glenohumeral joint occur less frequently in the general population compared with weight-bearing joints such as the hip, knee, or ankle. While glenohumeral chondral defects are generally a problem of the aging population, commonly arising from previous or concomitant shoulder trauma, glenohumeral instability, or postoperative chondrolysis,¹ they are becoming a more common problem in the young and active population, with an incidence ranging from 5% to 17%.^{2,3} Chondral defects are often missed on magnetic resonance imaging and are usually

incidental findings during diagnostic arthroscopy for another shoulder injury, such as rotator cuff tear or labral tear.⁴⁻⁷ These defects occasionally become symptomatic, warranting further management.^{2,4}

Many variables come into play when approaching the treatment of articular cartilage defects of the glenohumeral joint in the young, active population. A dilemma in treatment arises from the inability of the body to heal optimally due to the lack of blood supply to the articular cartilage.⁸ If left untreated, these lesions may progress to glenohumeral osteoarthritis, causing a long-term negative impact on the patient's function and quality of life. Total shoulder arthroplasty has been shown to be effective in relieving pain from articular cartilage defects; however, its application in the younger population is not a favorable choice due to the limited durability of the replaced joint.^{1,2} This has led to the development of various surgical options to better target cartilage defects in a less-invasive manner.

Several surgical techniques are now available for the management of articular cartilage defects of the glenohumeral joint, including arthroscopic debridement, microfracture, osteochondral autograft transplantation, allograft transplantation, and autologous chondrocyte implantation (ACI) or matrix-induced autologous chondrocyte implantation (MACI). Currently, there is

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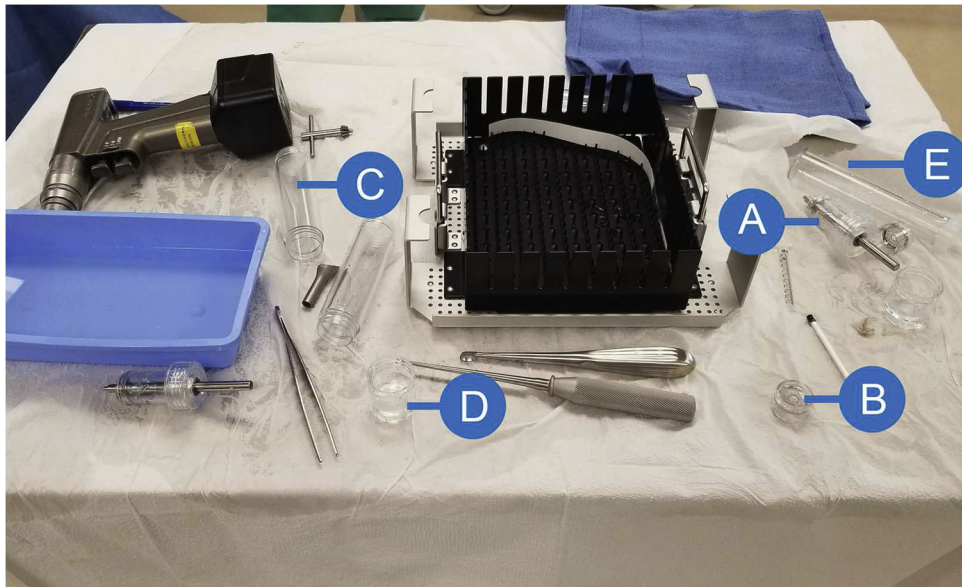


Fig 1. Reville CP System. Cartilage particulator device components used in the study. (A) Particulator. (B) Tissue holder. (C) Collection tube. (D) Tissue collection cup. (E) Filtration tube.

no clear consensus on which technique provides the best outcome in the glenohumeral joint, given the paucity of studies on long-term outcomes.^{2,4,9,10} In

addition, these techniques are not without individual drawbacks, such as multiple surgical sites, multistaged procedures, high cost, or nonautologous tissue.^{1,2,4}

Fig 2. Arthroscopic view from the posterior portal of left shoulder demonstrating cartilage harvesting from the superior humeral head adjacent to the rotator cuff insertion.

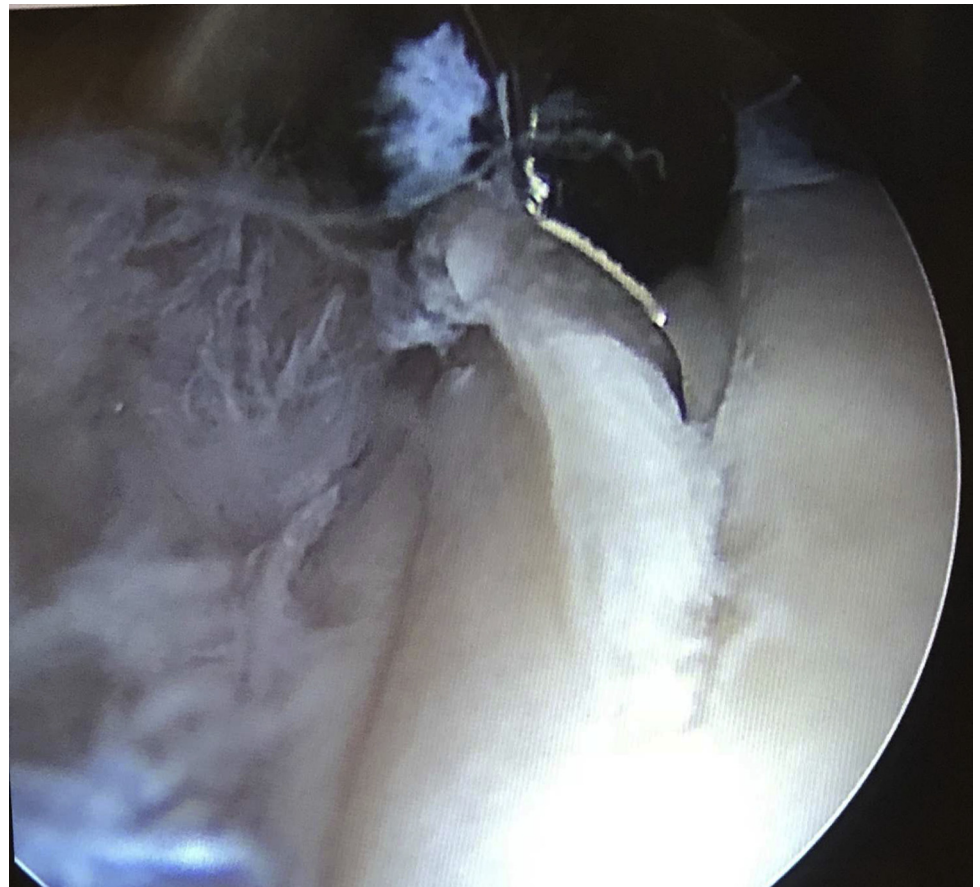




Fig 3. Cartilage paste postprocessing.

An innovative approach that applies the principle of new tissue formation for cartilage injuries has been applied in the knee¹¹ and shown to be effective¹²; however, the amount of tissue that can be reclaimed from intraoperative, autologous, glenohumeral harvesting has not been demonstrated. This approach allows for harvesting of cartilage from the non-load-bearing area in the joint, morselizing it, and applying it over the defect. Reveille CP (Exactech Inc., Gainesville, FL) (Fig 1) is a device that applies the principle of increasing surface area of cartilage particles to promote cartilage regeneration and prepares tissue grafts for immediate reimplantation. The aim of this study was to evaluate the volume and yield of morselized cartilage that can be harvested from the shoulder for immediate reimplantation and repair. We hypothesized that the amount of cartilage obtained would be sufficient to cover average sized defects of the glenoid and humerus.

Methods

This study was approved by the University of Florida Institutional Review Board (#201800819). Five healthy cadaveric shoulder specimens were obtained from MedCure (Portland, OR), stored in a -25.5°C freezer for an average of 7 days, and were thawed in a 4°C fridge over the course of 2 days before cartilage harvest. All 5 specimens were operated on by a single board-certified, fellowship-trained orthopaedic surgeon according to the procedure outlined to follow. Specimens were excluded if they demonstrated advanced arthritis. Patient demographic data were not available.

Technique

A standard diagnostic arthroscopy was performed on each cadaveric specimen to identify significant osteoarthritis or any pre-existing anatomic shoulder pathology. Direct visualization of the maximum end-range of shoulder flexion, extension, and abduction was directly observed arthroscopically to determine non-load-bearing cartilage. Cartilage was then harvested from the superior aspect of the humeral head medial to the insertion of the rotator cuff that did not demonstrate significant articulation during arthroscopic end range of motion testing. The cartilage was separated from the humerus with a curette in a medial to lateral direction starting adjacent to the insertion of the rotator cuff and long head of the biceps tendon (Fig 2). Graspers were used to retrieve and remove the cartilage flap from the anterior portal. The cartilage was added directly to the Reveille cartilage particulator to diminish fragment loss from the transfer. These steps were repeated until further harvest was no longer possible through arthroscopic means. The particulator was threaded onto a drill and tissue was morselized for at least 2 minutes at 1500 rpm. The total volume of processed cartilage reclaimed was measured using a syringe demarcated in 0.1-mL increments (Fig 3).

Outcomes of Interest and Analysis

The primary outcome of interest was volume of postprocessed cartilage (milliliters) that could be reclaimed from healthy cadaveric specimens. The theoretical size of a defect that could be covered with the reclaimed amount of cartilage paste was calculated using the theoretical cartilage defect coverage formula (Fig 4). The extrapolated mean from the samples was

$$defect\ size\ (cm^2) = \frac{cartilage\ paste\ (cm^3)}{layer\ thickness\ (0.1\ cm)}$$

Fig 4. Theoretical cartilage defect coverage formula. The formula used to estimate the theoretical size of a defect that could be covered with the reclaimed amount of cartilage paste assuming a target 1-mm monolayer.

Table 1. Amount of Cartilage Paste Available for Transfer

Sample No.	Volume of Cartilage After Processing, mL	Theoretical Defect Size Coverage, cm ²
1	2.4	24
2	1.0	10
3	2.0	20
4	2.0	20
5	1.9	19
Mean ± standard deviation	1.9 ± 0.5	18.6 ± 5.2

NOTE. Volume of cartilage paste following processing is reported for each specimen. Corresponding theoretical defect size coverage using formula from Figure 4 reported for each specimen.

compared with the mean estimated or calculated size of humeral head and glenoid defects reported in the literature.

Results

The total yield of cartilage paste following tissue processing that was obtained from the 5 glenohumeral joints ranged from 1.0 mL to 2.4 mL with a mean volume of 1.9 mL (Table 1).

Discussion

This cadaveric study demonstrated that adequate cartilage can be harvested to cover average and above average-sized defects of the glenoid and humerus in the shoulder. Using the conversion formula (Fig 4), our results demonstrate that the average volume of reclaimed processed cartilage yields 18.6 cm² of coverage. According to the literature, the mean glenoid defect size ranges from 1.12 to 2.73 cm², whereas the mean humeral defect size ranges from 4.22 to 6.00 cm² (Table 2).^{3,13-16} The mean articular cartilage depth of the humerus has been reported to be 1.24 mm, ranging from approximately 1.3 mm centrally and thinning to less than 1 mm along the periphery, and the mean depth of the glenoid fossa has been reported to be 1.88 mm.¹⁷

Regeneration of lost cartilage has been the ultimate goal for treatment of articular cartilage defects of the glenohumeral joint. While based on this general principle, the various approaches to surgical management of glenohumeral articular defects currently available

focus on regenerating articular cartilage through different mechanisms. In microfracture, access to underlying bone marrow is made to allow for the mesenchymal stem cells, growth factors, fibrin, and platelets to organize into a fibrous clot.^{1,4} This technique has shown good results for small lesions but may lead to fibrocartilage buildup, with limited efficacy for larger lesions and poor long-term results.^{3,13,14,18} In an osteochondral autograft procedure, osteochondral autograft plugs consisting of bone and cartilage are harvested, often from the knee, are then transferred and applied onto the defect.^{19,20} However, a common complication is harvest-site morbidity.¹ Osteochondral allograft transfers have primarily been used to repair large humeral head defects.^{15,21,22} This technique has been limited by graft resorption, rare disease transmission, and questionable chondrocyte viability.^{22,23} While primarily investigated for repair of cartilage defects in the knee joint, ACI and MACI have shown promising results and potential for treatment in the shoulder. In ACI, a sample of cartilage from the edge of the defect is collected and expanded *ex vivo* for 3 to 4 weeks. The cells are then implanted into the defect in hopes of regenerating the missing cartilage. MACI follows the same principle as ACI with the use of a custom autologous chondrocyte-infused implant. Both ACI and MACI are limited by the need for multiple surgeries and time for the chondrocytes to grow exogenously, delaying definitive treatment. In addition, these novel techniques are not without the negative aspects of greater costs and limited donor resources.^{1,4,15,24,25}

None of these techniques offer a single-site, single-staged procedure that uses a patient's autologous cartilage. To date, same-joint cartilage harvest and application has only been done in the knee.^{11,12} Massen et al.¹² reported satisfactory outcomes at 2-year follow-up in their cohort that underwent autologous minced cartilage transfer for chondral and osteochondral lesions in the knee. While the cohort was small, the authors concluded that it was a safe and cost-effective option in comparison with the other surgical techniques available. While this technique has not yet been studied clinically in the shoulder, it is reasonable to assume that it would also be associated with lower costs and no significant difference in morbidity when compared with other procedures.

Table 2. Summary of Average Glenohumeral Defect Sizes in the Published Literature

Source	Isolated Versus Combined Lesion	Glenoid Defect Size	Humeral Defect Size	Sample Size
Wang et al., 2018 ¹⁴	Isolated	1.53 cm ² (range, 1.00-3.75 cm ²)	5.20 cm ² (range, 4.00-7.80 cm ²)	n = 14
Camp et al., 2015 ¹⁶	Isolated	1.12 cm ²	—	n = 1
Buchmann et al., 2012 ¹⁵	Isolated	2.00 cm ²	6.00 cm ²	n = 4
Frank et al., 2010 ³	Isolated	1.66 cm ² (range, 0.40-3.75 cm ²)	5.07 cm ² (range, 1.0-7.84 cm ²)	n = 14
Millet et al., 2009 ¹³	Isolated	1.37 cm ² (range, 0.25-4.0 cm ²)	4.22 cm ² (range, 1.00-16.0 cm ²)	n = 25
	Combined	2.73 cm ² (range, 0.80-12.0 cm ²)	4.42 cm ² (range, 1.20-12.0 cm ²)	n = 6

Due to the avascular nature of cartilage tissue, the absorption of anabolic factors into the extracellular matrix is entirely dependent upon diffusion, which is limited by available surface area of the tissue. With increased surface area, bioactive factors present in minced cartilage grafts are better able to interact with marrow elements, such as mesenchymal stem cells, recruited to the lesion without the need to grow chondrocytes *ex vivo*.²⁶⁻²⁹ Tissue grafts prepared with Reveille CP (Exactech Inc.) are composed primarily of tissue particles between 0.3 mm and 1.0 mm in diameter, representing a 10-fold increase in surface area over that of intact articular cartilage, with exposure of cells on the surface of the particles. Fluorescent microscopy analysis has demonstrated high cellular viability in graft fragments following processing with Reveille CP. To avoid cartilage hypertrophy, a theoretical 1-mm layer of cartilage paste should be applied to a defect to imitate the true thickness of overlying cartilage, given limited subchondral bone involvement (Exactech internal study; data on file at Exactech). By use of the theoretical formula (Fig 4), the average volume of processed cartilage reclaimed in this study yielded enough cartilage paste for defect coverage. Even with large thickness subchondral defects or as high as 50% paste loss due to intraoperative transfer, this technique yields enough quantity of cartilage paste to fill glenoid or humeral defects similar in size to the previously reported averages in the literature. Thus, for typical glenoid or humeral cartilage defects, it would be reasonable to consider intraoperative cartilage reclamation with subsequent grafting as another technique for repair. Given the benefit of a single-stage and single-site procedure, this novel technique demonstrates significant potential as a future treatment option for glenohumeral cartilage defects.

Future Directions

These results warrant further studies to assess clinical practicality and outcomes for routine use. Currently, it is up to the experience and judgment of the surgeon to determine the acceptable and safe area of cartilage harvest in the humeral head. Development of a sterile device capable of drawing a physical line across cartilage would help better delineate the non-load-bearing zone of articular cartilage. As a result, this would maximize cartilage reclamation and patient safety in the application of this technique. In addition, the development of techniques or medical devices that optimize placement of the thin layer of processed cartilage could maximize filling capacity and further improve the potential of this procedure. Finally, the development of a definitive treatment protocol to obtain cartilage for immediate reimplantation will improve the time and cost-effectiveness associated with glenohumeral cartilage defects.

Limitations

This study is not without its limitations. First, the demographics of the 5 cadaver specimens were not available; therefore, variability in death, duration of storage, cartilage degeneration since time of death, mechanism of death, and functional status of the shoulder while alive could not be determined. However, all specimens were noted to have minimal-to-no osteoarthritis and deemed appropriate candidates for cartilaginous repair. The study's small sample poses a limitation as well; it is unknown how well this process could be replicated on a larger number of shoulders, particularly given the potential variability in the amount of cartilage that can be harvested without adverse outcomes. However, studies have demonstrated that the medialization of the rotator cuff footprint up to 10 mm leads to acceptable clinical outcomes during rotator cuff repair.^{30,31} Based on this information, the harvest was performed just medial to the rotator cuff insertion and did not exceed more than 10 mm medial from that point. We theorize similarly acceptable outcomes with this technique. Finally, creating a uniform 1 mm-thick layer during the grafting process may be challenging from a technical standpoint, thus overestimating the volume of cartilage paste actually needed for the procedure.

Conclusions

This study validated that through a single-stage surgical and processing technique it is possible to obtain a sufficient volume of reimplantable autologous morselized cartilage graft to address most glenohumeral articular cartilage defects.

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