ARTICLES

Treatment of Cartilage Defects in Young Shoulders: From the Lab to the Clinic

"Overall, this study provides a solid foundation for continued basic science research."

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Glenohumeral cartilage defects in the young patient are challenging clinical problems given the longer life expectancy after surgery of these patients and the greater demands their more vigorous lifestyles place on their shoulders. Numerous etiologies can lead to glenohumeral cartilage disease: trauma, instability, inflammatory arthridites, postinfectious degeneration, foreign body reaction, and glenohumeral chondrolysis.[1,2]

The initial treatment of glenohumeral cartilage disease is always nonsurgical, but when measures are needed beyond conservative management, there are a variety of treatment options available, including palliative, reparative, restorative, and reconstructive techniques for cartilage defects in the shoulder.

This study is one of a series from this institution that analyzes new bioconstructs and collagen matrices to augment cartilage in shoulder surgery. In this study, we evaluate whether autologous matrix-induced chondrogenesis (AMIC), which involves using a collagen I/III matrix with microfracture, can promote the formation of tissue with similar architecture to native cartilage by organizing adhesion, migration, and differentiation of mesenchymal stem cells to chondrocytes.

In order to understand the potential applications of this basic science research, we have employed a framework of clinical needs, which includes palliative, reparative, restorative, and reconstructive treatments, to guide a clinical management algorithm. Thus, we report on a novel treatment method and discuss the background framework into which it and other pieces are being fitted to improve care of shoulder disorders.

METHODS

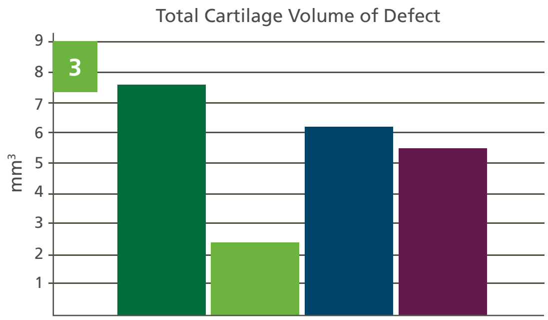
We hypothesized that a collagen I/III matrix superimposed on a chondral defect that has been concomitantly treated with microfracture will provide a superior medium on which functional cartilage will form and heal.

To test this hypothesis, we divided 12 rabbits into 3 groups. Each group underwent the same surgical approach to the rabbit glenohumeral joint, including incision and repair of the superior rotator cuff. Group 1, the surgical control, consisted of rabbits that underwent removal of the cartilage layer on the glenohumeral joint only. Group 2 rabbits underwent microfracture to the glenohumeral defect (Figure 1). Group 3 underwent the autologous matrix-induced chondrogenesis (AMIC) procedure: microfracture of the glenohumeral defect followed by the application of a collagen I/III matrix (Figure 2). Each rabbit had 1 operative shoulder and 1 control nonoperative shoulder. All operations were completed with the same exposure and closure.

The rabbits were then allowed to ambulate as tolerated. All rabbits recovered well from the procedure, indicating that the

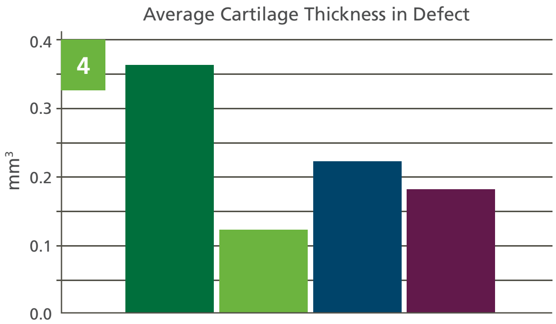
Figure 1. Microfracture to a rabbit glenoid.

Figure 2. Collagen I/III patch placed on the glenohumeral rabbit joint after microfracture.



	Pooled Average Total Volume
Native	7.62
Surg Cont	2.28
MicroFx	6.19
AMIC	5.43

Figure 3. Total cartilage volume of the glenohumeral defect in the rabbit joint.



	Pooled Average Mean Thickness (mm)
Native	0.36
Surg Cont	0.12
MicroFx	0.22
AMIC	0.18

Figure 4. Average cartilage thickness in the glenohumeral defect of the rabbit joint.

Abbreviations: Native, no surgery; Surg Cont, surgical control; MicroFx, microfracture; AMIC, autologous matrix-induced chondrogenesis

operations were tolerable from a physiologic standpoint and reaffirming the fact that a rabbit shoulder is a good model for glenohumeral surgical analysis. At 8 weeks post-op, we dissected and analyzed the glenohumeral joints of the rabbits. On inspection of the rabbits' glenohumeral joints, we found that they anatomically resembled the human shoulder joint with similar osseous and soft-tissue anatomy. Using a new micro-computed tomography (micro-CT) protocol, we also evaluated fill of the glenohumeral defect for each rabbit and every shoulder.

Based on the assumption that the glenoid cartilage would be approximately 100-500 µm in thickness, we set the micro-CT scanner to 20 µm resolution in all three spatial planes. These scans were carried out at 45 kV, 177 µA, and 300 ms integration time. The average scan consisted of approximately 412 slices. We used analysis of variance (ANOVA) results and Tukey post-hoc testing to determine significant differences between the normalized values.

RESULTS

The results for total cartilage volume and average cartilage thickness in both native and operative shoulders are displayed in Figures 3 and 4. There were no significant differences in the statistical results between all groups; however, there was a trend toward increased defect fill and thickness in the microfracture and AMIC groups (Groups 2 and 3, respectively). The topographical surface maps for the surgical control and AMIC procedures are shown in Figure 5 as an illustrative example of the subjective improvement in the AMIC fill patterns. There were also no significant trends in the attenuation values of the defect fill. Post-hoc power analysis showed each group would need to have 10 specimens in order to find statistical differences.

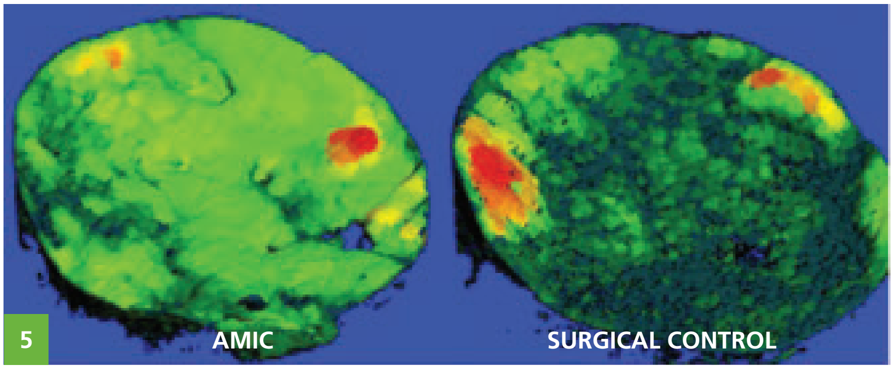


Figure 5. Topographical maps of the cartilage surface in the two different treatment groups.

Figure 6. Rabbit glenohumeral joint.

DISCUSSION

The current study evaluates whether a collagen I/III matrix with microfracture can promote the formation of tissue with similar architecture to native cartilage by organizing adhesion, migration, and differentiation of mesenchymal stem cells to chondrocytes. The data suggest that both microfracture and autologous matrix-induced chondrogenesis (AMIC) have the ability to fill a glenohumeral cartilage defect in a rabbit model significantly more than the surgical control, based on micro-CT data.

Although the current study does not reveal significant differences, there are some very important conclusions that can be drawn. One, further research is needed to characterize the trends seen in this study. We currently have a much larger trial underway that will use histology and MRI to corroborate the results reported here. Two, the rabbit glenohumeral model is a very good *in vivo* model to study glenohumeral cartilage defects (Figure 6). Overall, this study provides a solid foundation for continued basic science research.

However, basic science research in isolation cannot address the issue of glenohumeral cartilage defects without clinical corollaries. In order to understand the potential applications of this basic science research, we reviewed the aforementioned areas of palliative, reparative, restorative, and reconstructive techniques in the shoulder joint to provide a framework to guide a clinical management algorithm.

PALLIATIVE TREATMENTS

Palliative techniques for the management of glenohumeral cartilage disease are designed to alleviate symptoms without replacing or restoring the injured articular cartilage. These techniques consist primarily of arthroscopic debridement, capsular release, lavage, and loose body removal. Arthroscopic debridement is appealing because it is technically straightforward, has low surgical morbidity, and does not preclude other, more advanced, restorative and reconstructive interventions in the future. In a few published series, arthroscopic debridement has led to good or excellent results in roughly 80% of patients at short follow-up intervals.[3-5] Cameron et al[6] reported on a series of patients with grade IV osteochondral defects and found that 88% experienced significant improvement in pain and function for an average duration of 28 months. Weinstein et al also reported 80% good or excellent results at a mean follow-up of 34 months.[5] The largest series in the literature was reported by Van Thiel, Romeo, Verma, Cole et al.[4] The authors retrospectively reviewed 81 patients who underwent arthroscopic debridement for glenohumeral osteoarthritis. Of the 81 patients, 71 were available for follow-up at an average of 27 months, and 58 of the 81 (82%) were satisfied with the results of the surgery and would have it again. They also experienced a statistically significant improvement in postoperative functional outcome scores and a decreased level of pain. Of the 71 patients, 16 (23%) experienced surgical failures and required arthroplasty at a mean of 10.1 months after debridement. Grade IV bipolar disease, joint space less than 2 mm, and the presence of large osteophytes constituted the most significant risk factors for failure. Overall, arthroscopic debridement is a very reasonable and predictable first-line surgical option that offers relief of pain and improvement in functionality in approximately 80% of cases.

REPARATIVE TREATMENTS

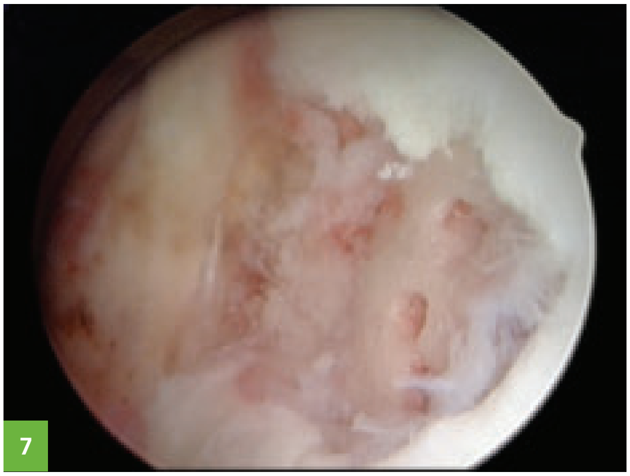
Reparative treatment includes marrow stimulation techniques like chondroplasty, subchondral drilling, and microfracture to replace the damaged cartilage with fibrocartilage (Figure 7). However, despite its reported effectiveness in the knee joint, we are aware of only three series that report clinical outcomes following microfracture in the shoulder joint.[7-9]

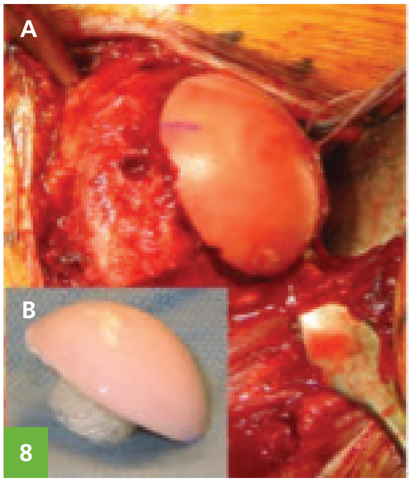
Siebold et al[9] and Millet et al[8] reported on small series of patients that underwent microfracture for full-thickness chondral defects. At final follow-up there was a significant improvement in functional scores with an approximately 20% rate of revision procedures.

Our experience has been similar: Frank, Van Thiel, and Cole et al[7] reported minimum 12 months (mean, 28 months)

Figure 7. Microfracture of the glenoid in a young patient.

Figure 8. Humeral head allograft in a patient with severe degeneration of the humeral head. **A,** Allograft implanted into the patient's humerus. **B,** Inset showing humeral head allograft prior to implantation.





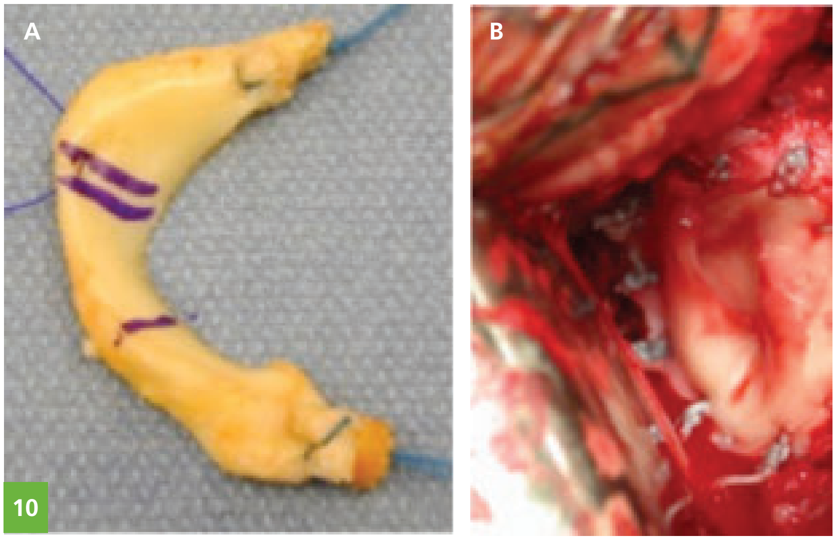


Figure 9. Autologous chondrocyte implantation to the humeral head.

Figure 10. Lateral meniscus allograft (LMA) **A,** LMA that will be used to resurface the glenoid. **B,** LMA sutured to the glenoid.

follow-up on 16 patients (17 shoulders) who underwent arthroscopic microfracture of the humeral head or glenoid surface. The 14 patients that were available for follow-up had statistically significant improvements in pain and function. Of the 16 patients, 3 (20%) had subsequent shoulder surgery and therefore, their initial surgeries were considered to be failures. Additional research is needed before definitive statements can be made, but microfracture does appear to be a viable treatment option for select patient populations.

RESTORATIVE TREATMENTS

Restorative treatments aim to reestablish hyaline or hyaline-like cartilage by transferring hyaline cartilage via osteochondral grafting (autograft or allograft) or by growing hyaline-like cartilage using autologous chondrocyte implantation (ACI). At present, osteochondral autograft and ACI require a shoulder arthrotomy and a second surgical procedure at the knee for graft harvest. Consequently, both procedures are more invasive and more technically demanding, and they expose the patient to significantly greater surgical morbidity than arthroscopic palliative or reparative techniques. Therefore, restorative modalities are best reserved for the young, active individual with a distinct chondral lesion of the humerus or glenoid who has already failed conservative, palliative, and reparative treatment.

Habermeyer et al[10] have published good results for 7 patients who received osteochondral autograft transfer from the knee to the shoulder with almost 9-year follow-up. The authors based their results on both functional as well as MRI criteria. Osteochondral allograft transfer employs a similar technique, matching a donor plug to a recipient site, but without the concern for donor-site morbidity. Therefore, allograft transfer can be used to treat more sizable lesions than can be treated effectively by autograft transfer.

Given this versatility of osteochondral allografts, a number of case reports describe the use of side- and size-matched osteochondral allografts for large Hill-Sachs lesions at the site of recurrent instability.[11-13]

Cole and McCarty[14] took the allograft transfer one step further and completed an osteochondral allograft humeral head resurfacing in combination with a lateral meniscal allograft glenoid resurfacing (Figure 8). In this case report, a 16-year-old girl with symptomatic bipolar glenohumeral chondrolysis after arthroscopic thermal capsulorrhaphy was treated with the meniscal and osteochondral allografts. At 2-year follow-up, the patient reported complete resolution of her shoulder pain, and radiographs showed maintenance of the glenohumeral joint space.

Romeo et al[15] published a case report on the use of ACI in a 16-year-old baseball player with a humeral head lesion (Figure 9). Restoration was performed with a 2-stage harvest (knee) and implantation (shoulder) technique with harvest of a periosteal graft from the tibia. At 1 year, the patient had full range of motion without any pain. These case reports offer hope to young patients with end stage disease of the glenohumeral joint, but further research is needed to determine the long term outcome in a larger patient population.

RECONSTRUCTIVE TREATMENTS

Reconstructive techniques can use a combination of prosthetic and biologic components to repair the humeral head and glenoid and include soft-tissue interposition with fascia lata autograft, allograft Achilles tendon, allograft human skin (GraftJacket; Wright Medical Technology, Inc., Arlington, Tennessee), and lateral meniscal allografts. Experience with these techniques is generally limited to a few institutions and literature reporting long-term outcomes is sparse.

Burkhead and Hutton proposed biological resurfacing of the glenoid with the interposition of soft tissue as a means of improving the outcome of hemiarthroplasty in young patients.[16] Their good results were supported by Huijsmans et al,[17] who used a similar technique involving the GraftJacket. Yamaguchi et al[18] proposed the use of a lateral meniscal allograft (LMA) as the interposition material (Figure 10). The lateral meniscus is an attractive option given its favorable shape, load-bearing characteristics, and durability compared with other interposition materials.

Our research on LMA published in 2007[19] has questioned these good results. In this study, 45 consecutive patients were treated with hemiarthroplasty in conjunction with glenoid resurfacing with either LMA or GraftJacket. Short-term follow-up data (minimum 18 months) of 30 patients who underwent LMA resurfacing demonstrated promise; of those 30 patients, 28 (94%) were satisfied with their clinical outcome. However, at mean follow-up of 2.8 years, 21 of 41 patients (31 LMA, 10 GraftJacket) had experienced a clinical failure. Clinical failure was defined by conversion to total shoulder arthroplasty (TSA) (8 cases), recommended conversion (5 cases), the American Shoulder and Elbow Surgeons (ASES) score ≤ 5 (5 cases), disabling pain/loss of function (2 cases), or graft removal (1 case).

These results illustrate the need for both appropriate patient selection and continued research.

CONCLUSION

No consensus exists in the literature regarding the most appropriate treatment for glenohumeral chondral lesions in the young patient. The purpose of this study was two-fold: (1) to report the initial results of a novel technique to manage cartilage defects in the rabbit glenohumeral joint and (2) to synthesize clinical data regarding the management of glenohumeral lesions in young patients. We hypothesize, and our data suggest but have not yet proven, that a collagen I/III matrix superimposed on a chondral defect that has been concomitantly treated with microfracture will provide a superior medium on which functional cartilage will form and heal. Future research will continue to yield new treatment modalities with the goals of increasing function and improving outcomes. ■

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Disclosures for the preceding article are listed on p. 46.