Clinical Outcome of Autologous Chondrocyte Implantation for Failed Microfracture Treatment of Full-Thickness Cartilage Defects of the Knee Joint

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Background: Although various factors have been identified that influence outcome after autologous chondrocyte implantation (ACI), the relevance of prior treatment of the cartilage defect and its effect concerning the outcome of second-line ACI have not been evaluated to a full extent.

Hypothesis: Autologous chondrocyte implantation used as a second-line treatment after failed arthroscopic microfracturing is associated with a higher failure rate and inferior clinical results compared with ACI as a first-line treatment.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 28 patients with isolated cartilage defects at the knee joint were treated with ACI after microfracture as a first-line treatment had failed (failure defined as the necessity of reintervention). These patients were assigned to group A and compared with a matched-pair cohort of patients of identical age, defect size, and defect location (group B). In which ACI was used as a first-line treatment. Failure rates in both groups were assessed. Postoperative knee status was evaluated with the International Knee Documentation Committee (IKDC) score and Knee injury and Osteoarthritis Outcome Score (KOOS), and sporting activity was assessed by use of the Activity Rating Scale. Mean follow-up times were 48.0 months (range, 15.1-75.1 months) in group A and 41.4 months (range, 15.4-63.6 months) in group B. Differences between groups A and B were analyzed by Student t test.

Results: Group A had significantly greater failure rates (7 of 28 patients) in comparison with group B (1 of 28 patients; \( P = .0241 \)). Mean (SD) postoperative IKDC scores revealed 58.4 (22.4) points in group A with a trend toward higher score results (69.0 [19.1] points) for patients in group B (\( P = .0583 \)). Significantly different results were obtained for KOOS pain and activity of daily living subscales, whereas the remaining KOOS subscales did not show significant differences. Despite the significantly higher failure rate observed in group A, those patients did not participate in fewer activities or perform physical activity less frequently or at a lower intensity.

Conclusion: Autologous chondrocyte implantation after failed microfracturing appears to be associated with a significantly higher failure rate and inferior clinical outcome when compared with ACI as a first-line treatment.

Keywords: microfracture; autologous chondrocyte implantation; articular cartilage; knee joint; IKDC; KOOS; Activity Rating Scale

Once injured, articular cartilage possesses poor to no spontaneous healing potential depending on defect depth and size.3 When left untreated, many full-thickness defects progress to symptomatic joint degeneration.18 In recent years, a number of promising surgical interventions have been established. These can be either reparative, such as narrow stimulation techniques (eg, microfracture, drilling, abrasion arthroplasty), or restorative in nature, where autologous chondrocyte implantation (ACI) has become a well-established technique.6 Application of one or a combination of those methods has become almost inevitable to achieve satisfactory clinical results because no existing medication or other nonoperative regimen substantially promotes the healing process.8

Clinical results and outcome of reparative and restorative techniques have been carefully investigated and, apart from a general question as to why articular chondrocytes possess poor healing potential, predictors and factors influencing success rates of the techniques have been established. The best clinical results of the microfracture technique, for example, can be found in young patients...
with small-diameter traumatic lesions not affecting subchondral bone. Microfracture has been reported to provide effective short-term functional improvement of knee function, but insufficient data are available on its long-term results. In those cases where an initial microfracture fails, decision making on which subsequent technique to choose becomes increasingly difficult. To date, the technique of choice mostly will be a restorative tissue engineering approach such as the implantation of autologous chondrocytes into the defect area. Autologous chondrocyte implantation has become an accepted surgical procedure for the treatment of full-thickness cartilage defects of the knee joint. Its clinical outcome and success rates as a subsequent technique after a failed marrow stimulation technique in the same location, however, have been discussed controversially. Zaslav et al. reexamined patients with failed primary non-ACI surgery and subsequent ACI procedures. Non-ACI techniques consisted mainly of debridement alone (43% of patients) or marrow stimulation techniques (MSTs) such as microfracturing (27%) or subchondral drilling (16%). The study reported satisfactory results for patients with large chondral lesions with failed prior cartilage treatment who underwent a subsequent ACI procedure.

Minas et al., on the other hand, found an increased failure rate of ACI after previous treatment with marrow stimulation techniques. Similar to the previous study, marrow stimulation techniques comprised microfracture (20% of patients), drilling (28%), and abrasion arthroplasty (27%). One possible explanation for those conflicting results could be that a combination of different primary techniques foregoing subsequent ACI procedures was analyzed.

The aim of the current study was therefore to perform a detailed clinical analysis comparing clinical success rates of ACI patients in general, particularly in those who had undergone a failed microfracture, with a subsequent ACI surgery performed in the same location.

METHODS AND PATIENT SELECTION

Study Design and Cohort Selection

A retrospective matched-pair study design was used to examine the efficacy and clinical results of ACI in patients with failed prior microfracture for articular cartilage defects of the knee joint. Between August 2000 and September 2008, 252 patients were treated with ACI for isolated full-thickness defects of the knee joint. In all cases, the final decision for ACI was made during routine arthroscopy of the affected knee joint based on prior magnetic resonance imaging (MRI) diagnostics. Patients were excluded from the study if they had any of the following: a history of partial or total meniscectomy, a history of inflammatory joint disease and malalignment of more than 5 degrees, or ACL insufficiency or reconstruction. To make a better comparison between individual patients, we included in this study only ACI procedures in which a chondroide (Geistlich, Wolhusen, Switzerland) membrane was used to cover the cartilage defect after it had been filled with autologous chondrocytes. Of the remaining patients, 28 were identified as having received an initial arthroscopic microfracture in the same location of a subsequent ACI because of unsatisfactory clinical results. Those patients were assigned to group A. Following the routine of a matched-pair analysis, patients were matched by sex, age, defect location, and defect size to a cohort of more than 200 ACI patients who had undergone ACI as a primary treatment. Patient names were blinded and individually matched by an independent scientist without insight into patient history or clinical complaints, beginning with nominal parameters (sex, defect location, followed by metric parameters (age, defect size)). Those patients were assigned to group B. For all patients, both from the study group and the control group, a minimum follow-up time of at least 12 months was required. Patients were contacted by postal questionnaire, to which 100% of patients (28/28) in group B replied. The reply rate in group A was 96.4%, in which 1 patient of 28 failed to respond to the questionnaire.

International Knee Documentation Committee, Knee Injury and Osteoarthritis Outcome Score, and Activity Rating Scale

At the time of follow-up, overall and everyday knee condition was assessed clinically with the help of the International Knee Documentation Committee (IKDC) score. Furthermore, the condition of the knee in 5 domains was evaluated with the help of the Knee injury and Osteoarthritis Outcome Score (KOOS). Those domains included pain (KOOS-P), symptoms (KOOS-S), sports and recreation ability (KOOS-SR), knee-related quality of life (KOOS-Q), and activities of daily living (KOOS-A). Next to an individual calculation of each domain's score, we did not calculate a total KOOS score to avoid strong influence by KOOS-Q but rather used a prespecified KOOS4 score, which was calculated as follows: KOOS4 = (KOOS-P + KOOS-S + KOOS-SR + KOOS-Q)/4, according to a recent publication by Proebst et al.

In addition, a series of questions were included in the questionnaire to address patients' baseline pain and grade of satisfaction after ACI. Whenever applicable, a visual analog scale (VAS; range, 0-10) was used to estimate patients' subjective knee status. Baseline pain was evaluated on the VAS, ranging from 0 (no pain) to 10 (maximum pain). Estimation of the knee's baseline status was approached ("How does your knee feel today?"; 0 = very bad to 10 = excellent), as well as the subjective feeling of improved knee status as a result of ACI surgery ("How does your knee feel today compared to before ACI?"; 0 = no improvement to 10 = maximum improvement). In addition, patients were asked if they would make the same choice concerning the ACI surgery again ("Having experienced the effects and results of ACI, would ACI still be your treatment of choice?"). An additional question was raised to address patients' subjective knee status during the year before ACI ("How did your knee feel during the year before ACI?"; 0 = very bad to 10 = no complaints).
TABLE 1
Patient Demographics and Baseline Characteristics for Patients With Microfracture Prior to Autologous Chondrocyte Implantation (Group A) and Matched-Pair Control Patients (Group B)*

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>28</td>
<td>28</td>
<td>NA</td>
</tr>
<tr>
<td>Age, y, mean ± SD (range)</td>
<td>34.1 ± 9.0 (14.3-45.8)</td>
<td>33.6 ± 10.1 (19.2-54.2)</td>
<td>.491</td>
</tr>
<tr>
<td>Men/women, No.</td>
<td>16/12</td>
<td>16/12</td>
<td>NA</td>
</tr>
<tr>
<td>Defect size, cm², mean ± SD (range)</td>
<td>4.6 ± 2.7 (1.5-7.5)</td>
<td>4.7 ± 1.6 (2.5-9.0)</td>
<td>.308</td>
</tr>
<tr>
<td>Location in knee, No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFC</td>
<td>16 (57.1)</td>
<td>16 (57.1)</td>
<td>NA</td>
</tr>
<tr>
<td>LFC</td>
<td>2 (7.1)</td>
<td>2 (7.1)</td>
<td>NA</td>
</tr>
<tr>
<td>Trochlea</td>
<td>7 (25.0)</td>
<td>7 (25.0)</td>
<td>NA</td>
</tr>
<tr>
<td>Patella</td>
<td>3 (10.7)</td>
<td>3 (10.7)</td>
<td>NA</td>
</tr>
<tr>
<td>Follow-up time, mo, mean ± SD (range)</td>
<td>48.2 ± 17.1 (15.1-75.1)</td>
<td>41.4 ± 17.0 (15.4-83.8)</td>
<td>.467</td>
</tr>
<tr>
<td>Number (%) of failures</td>
<td>7 (25.0)</td>
<td>1 (3.6)</td>
<td>.024*</td>
</tr>
</tbody>
</table>

*LFC, lateral femoral condyle; MFC, medial femoral condyle; NA, not applicable.

*indicates statistically significant differences measured with a 2-tailed Student t test.

Sports and recreational activity were assessed using a previously applied Activity Rating Scale (ARS) questionnaire for the assessment of lifetime, preoperative, and postoperative engagement in 20 different sports and recreational activities. The questionnaire was modified according to previous work by Salzmann et al. by including a lifetime sports assessment. It also inquired about the patient's overall satisfaction with surgery (1 = very satisfied, 2 = satisfied, 3 = partially satisfied, 4 = not satisfied) with respect to sports activities.

Failure Rate/Survival Rate

The need for revision surgery in the same location where the initial ACI had been performed due to pain and severe discomfort was defined as failure. Those cases were characterized by MRI findings in terms of persistence of subchondral edema, insufficient regenerative tissue, and elevated subchondral bone.

Total numbers of patients from group A with failure were assessed and set in relation to control group B. A Kaplan-Meier survival graph was constructed to visualize failure/survival.

Autologous Chondrocyte Implantation

The steps of the ACI procedure have been described in detail elsewhere, together with a detailed protocol of the steps necessary for the processing of chondrocytes. After in vitro expansion, chondrocytes were reimplanted into the original defect area in a second operation. Chondro-Gide (Geistlich) membranes were used in every case. The chondrocyte suspension (1 million cells per cm²) was then injected into the defect area. All patients were mobilized on the first postoperative day. Continuous passive motion was recommended to all patients after ACI from day 1 postoperatively for 6 weeks. Limited weightbearing was recommended for 6 weeks after ACI. Individual limits of flexion were also recommended depending on the exact defect location to avoid early exposure of the regenerative cartilage to axial compression and shear forces.

Statistical Analysis

For statistical analysis, GraphPad Prism software (Version 5; GraphPad Software, La Jolla, California) and Microsoft Excel XP (Microsoft, Redmond, Washington) were used. For statistical evaluation, 2-tailed Student t tests were performed to reveal differences between groups A and B. Survival curves were shown as a Kaplan-Meier curve and survival rates calculated using a χ² test. P values <.05 were considered significant; those <.01 were considered strongly significant.

RESULTS

Cohort Characteristics

As required for a matched-pair analysis, groups A and B were very similar with regard to patient age at chondrocyte implantation, sex, defect size, and follow-up interval. Those basic parameters were available for all patients. In addition, defect locations were matched, with the medial femoral condyle (MFC) being affected in more than 50% of all patients (Table 1). The reply rate to the postal questionnaire was 100% in group B and 96.4% (27/28) in group A, in which 1 patient's response was not available. Mean (SD) follow-up times did not differ significantly, with 48.0 (17.8) months (range, 15.1-75.1 months) in group A and 41.4 (17.0) months (range, 15.4-83.6 months) in group B (P = .467).

IKDC Score Outcome Measures

All outcome measures are summarized in Table 2 and Figure 1. In summary, postoperative knee function assessed by IKDC score showed a trend toward higher
TABLE 2
Postoperative Knee Status Surveyed by the International Knee Documentation Committee (IKDC) Score and Knee Injury and Osteoarthritis Outcome Score (KOOS)³

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A</th>
<th>Group B</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>27</td>
<td>28</td>
<td>NA</td>
</tr>
<tr>
<td>IKDC score, mean ± SD</td>
<td>58.4 ± 22.4</td>
<td>69.0 ± 19.1</td>
<td>.053</td>
</tr>
<tr>
<td>KOOS score, mean ± SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>72.7 ± 22.3</td>
<td>80.0 ± 16.7</td>
<td>.083</td>
</tr>
<tr>
<td>Sports/recreation</td>
<td>69.2 ± 25.6</td>
<td>80.1 ± 16.4</td>
<td>.034³</td>
</tr>
<tr>
<td>ADL</td>
<td>43.7 ± 31.3</td>
<td>56.4 ± 28.4</td>
<td>.061</td>
</tr>
<tr>
<td>QOL</td>
<td>78.5 ± 19.3</td>
<td>86.3 ± 14.3</td>
<td>.024³</td>
</tr>
<tr>
<td>KOOS₄</td>
<td>41.6 ± 24.6</td>
<td>48.9 ± 23.7</td>
<td>.133</td>
</tr>
<tr>
<td>VAS subjective pain before ACI (0-10), mean ± SD</td>
<td>3.4 ± 1.9</td>
<td>3.4 ± 1.9</td>
<td>.014³</td>
</tr>
<tr>
<td>VAS subjective knee function after ACI (0-10), mean ± SD</td>
<td>6.2 ± 2.2</td>
<td>6.9 ± 2.2</td>
<td>.032³</td>
</tr>
</tbody>
</table>

³ACI, autologous chondrocyte implantation; ADL, activities of daily living; NA, not applicable; QOL, quality of life. KOOS₄ was calculated as (KOOS-P + KOOS-S + KOOS-SR + KOOS-Q)/4; VAS (visual analog scale) was assessed for knee pain before ACI and knee function after ACI on a scale ranging from 0 (no knee pain, poor knee function after ACI) to 10 (maximum pain, excellent knee function after ACI).

KOOS Outcome Measures

Patient reports of knee symptoms and function (KOOS) indicated an inferior clinical outcome in all domains for patients with prior microfracture (group A) when compared with the results of group B. Significantly lower score values were found for KOOS pain and activities of daily living subscales, whereas the remaining subscales showed lower score results for group A patients but failed to reach statistical significance (Table 2). Consequently, the calculated KOOS₄ score closely missed statistical significance between both groups, even though a trend toward higher score values in favor of group B was observed (P = .0583).

Global VAS Score and Specific Questions

Patients' subjective appreciation of their knee function before ACI, measured on the VAS, was significantly lower in group A (3.4 ± 1.9 points; range, 0-8) than in group B (4.4 ± 2.5 points; P = .014). In group A, two-thirds of patients (66.7%) reported that ACI led to an improvement of knee symptoms even though pain at exposure at the time of questioning, measured on the VAS, still averaged 4.21 ± 2.44 points. Overall satisfaction with surgery averaged 6.2 ± 2.3 points and improved significantly in comparison with before ACI (P < .001). Consecutively, a total of 19 patients (70.4%) reported that having experienced ACI's clinical outcome, they would make the same decision toward ACI again.

In group B, a majority of 20 patients (71.4%) reported that ACI led to an improvement of knee symptoms. Patients from this group reported less baseline pain (3.4 ± 2.7 points) when compared with group A. Differences did not reach statistical significance. Overall satisfaction with surgery averaged 6.9 ± 2.2 points in group B, indicating that those patients were significantly more satisfied with ACI than were patients from group A (P = .032). Comparison of patients' knee status before ACI (4.4 ± 2.5 points) and at the time of questioning showed that patients from group B experienced a significant increase in knee function (P < .001). Consequently, the majority of those
Activity Rating Score

Taken together, during their lifetimes, 94.5% of all patients (groups A and B) were engaged in different sports and recreational disciplines. Activity levels in groups A and B proved to be very similar. Patients in group A participated in sporting activities twice weekly, with a total exercise time per week of 3.7 ± 2.6 hours, on average, after surgery in comparison with an average of 3.6 ± 4.3 hours twice weekly the year before ACI (P = .917).

Patients in group B participated in sporting sessions 3 times per week, on average, with a total exercise time per week of 4.3 ± 3.6 hours after ACI in comparison with 5.6 ± 5.1 hours for 3 sessions per week, on average, the year before surgery (P = .273).

In group A, a total of 10 patients (37.0%) were engaged in competitive sports during their lifetimes, with only 1 patient (3.7%) being able to continue competition during the year before ACI and after surgery. In group B, a total of 8 patients (26.6%) were engaged in competitive sporting activities during their lifetimes, of whom a total of 2 (7.1%) were able to participate in such activity the year before surgery. At the time of survey, no patient participated in competitive sporting activities.

Neither in group A nor group B did the distribution patterns among the top 20 cited sports activities change significantly for lifetime, preoperative, and postoperative periods, with the exception of soccer and tennis (see the Appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental). In general, high-intensity activities such as alpine skiing or soccer had to be abandoned in both groups preoperatively and usually were not continued after surgery. For activities with continuous motion, where intensity can easily be chosen individually (eg, cycling, jogging, swimming, fitness), patients either continued these after surgery or started to participate in them.

Inquiry about the patients' overall satisfaction with surgery with respect to sports activities revealed that in group A, 11.1% of all patients (group B: 11.7%) were very satisfied, whereas the vast majority of patients were either satisfied (33.3%) or partially satisfied (20.6%; group B: 26.6% and 32.1%, respectively). A total of 7 patients (26.9%) reported that ACI did not lead to satisfactory results (group B: 28.6%).

Failure Rate/Survival Rate

Failure rate was defined as the need for revision surgery. Immediate postoperative complications (eg, infection) were not observed in either group and did not therefore have an effect on failure rate. One-fourth (25.0%) of the patients in group A needed revision surgery at the same location as the previous ACI because of unsatisfactory clinical results. In comparison, the failure rate in group B was significantly lower, with only 1 patient (3.6%) needing surgical re-intervention (P = .054; Figure 1).

Consecutively, calculation of overall survival rate during the total time of follow-up showed a significantly greater ACI survival in group B than in group A (P = .0076).

DISCUSSION

With the help of this matched-pair analysis, we are able to demonstrate that in patients with failed microfracture treatment of the knee joint, a subsequent ACI procedure is less likely to produce satisfactory clinical results in comparison with patients with ACI as a primary treatment. This does not lead to the conclusion that microfracture should not be considered for appropriate indications. According to the current guidelines,6 microfracture is an effective treatment if applied in small full-thickness cartilage lesions. Evaluation of success rates in microfracturing, however, was not the purpose of the present study because only cases of failed microfracturing were selected for this study, regardless of the number of patients treated successfully with arthroscopic microfracturing. In addition, because revision ACI after failure of other primary procedures was not studied, our study cannot determine whether the results of revision ACI after failed microfracture are better or worse than revision after the failure of other primary procedures.

Since the introduction of ACI, several studies have described factors that influence its clinical outcome. For example, the prognostic relevance of defect location has been studied in depth. Obviously, defects of the MFC appear to be associated with superior clinical outcome when compared with patella defects.22,25 Furthermore, advanced degeneration grade of the joint and greater patient age appear to be associated with inferior knee function after ACI when compared with younger patients with traumatic defects.11,22,28,31 Still, information on the prognostic relevance of operative treatment before ACI is still elusive. A recent study by Minas et al17 observed an increased failure rate of ACI after treatment with marrow stimulation techniques before ACI. Interestingly, this study described a higher failure rate after bone marrow stimulation (BMS) techniques in general without specifically focusing on microfracturing, which is the most common BMS technique. Furthermore, no detailed assessment regarding the patients' clinical knee function after ACI can be found in this study.

In the recently published Study of the Treatment of Articular Repair (STAR) clinical trial,32 on the other hand, researchers did evaluate clinical knee scores and reported that patients with failed prior cartilage treatments can expect sustained and clinically meaningful improvement in pain and function after ACI. This study, however, did not include patients without prior cartilage surgery, which could have been directly compared with this study's cohort. Therefore, no direct comparison between patients with treatment prior to ACI and without such treatment was possible.

The study by Minas et al17 and the STAR trial32 are extensive studies with great patient numbers that were able to make important contributions to our current...
knowledge concerning prognostic factors of ACI. We believe that the gain of knowledge obtained from these studies could have been even greater if clinical assessment of knee function (Minas et al) and matched-pair control patients (STAR trial) had been included. In light of these observations, we fear that the prognostic relevance of marrow stimulation techniques before ACI might still not be completely understood and should remain the subject of further research efforts.

Therefore, we decided to initiate a clinical study that evaluates clinical knee function in patients who underwent a marrow stimulating technique in the same location as a subsequent ACI and set the outcome in relation to matched-pair control patients. By including only microfracturing as the surgical technique before ACI, we aimed to simplify our analysis, therefore presenting a more distinct conclusion. Also, from our point of view, a matched-pair analysis appeared to be an appropriate tool to study such a controversially discussed subject and should be able to produce representative and significant data.

As a valuable addition, the ARS inquired about patients' sports and recreational activities during their lifetime, the year before surgery, and at the time of follow-up.

Our questionnaire was further upgraded through a number of questions that, although subjective in nature, were found to be highly informative. Next to the extensive set of clinical and functional information acquired with the help of the IKDC, KOOS, and ARS, we also decided to investigate the general parameter "failure rate," defined as the necessity to perform an additional cartilage surgery in the area of the former ACI because of an unsatisfactory clinical outcome.

We chose not to use a total KOOS score because it has poor content validity and might be strongly influenced by the daily-function subscale KOOS-A because it accounts for 17 of 42 items. Total KOOS is therefore neither suggested nor validated. Our data greatly support this recommendation.

Autologous chondrocyte implantation, being a well-established and mostly successful treatment for articular cartilage defects, is often chosen as a second-line treatment. Taking the inferior results of the MST group into account, we believe that the decision for ACI should be made more liberally and that performing a microfracture procedure in situations where ACI is possible should be avoided.

This is further supported by recent studies where osteochondral lesions have been associated with poor clinical outcome after cartilage surgery. An explanation might be that a thickening of the subchondral plate after microfracturing makes articular cartilage more susceptible to damage from shear forces. Thus, violation of subchondral bone might convert a chondral problem into an osteochondral problem.

The defect's size influences the choice of its treatment. The average size of cartilage lesions in both groups was 4.5 cm², a size where inferior results have been reported for microfracturing. Nevertheless, at the time of failure and therefore at the time of ACI, the mean defect size was larger than during the initial microfracturing. This is important, as the conclusion that a mean defect size of 4.5 cm² in the present study was not appropriate for arthroscopic microfracturing is not valid. Microfracturing clearly has its indications for smaller defects whereas ACI is technically difficult and not generally recommended. Here, satisfactory clinical results have been associated with the microfracture procedure. Recommendations for microfracturing can therefore be made for small defects, preferably in the femoral condyles of younger patients.

However, we are fully aware that once a microfracture procedure has failed, treatment options are limited. As shown in this study, ACI even in this setting is able to provide satisfactory clinical results, as measured by the IKDC and KOOS. Still, the ARS questionnaire revealed that treatment with microfracture and subsequent ACI led to a significant reduction in sporting activities in comparison with before surgery. However, these changes were equally pronounced in both groups despite the significantly higher failure rate found in group A. From our point of view, this observation indicates that we are dealing with a highly selective group of patients. This is further supported by our observation that in both groups, the percentage of patients participating in high-level sports such as downhill skiing or mountain biking did not change significantly from preoperative to postoperative. Activities with intense rotating movement of the knee joint and sudden de- and acceleration, such as tennis and basketball, had to be abandoned by most patients postoperatively.

Concerning general limitations of the present study, analogous to previous studies, one might be its retrospective design as a result of not having any preoperative functional data concerning the patients' knees. Because these data were not available, differences between both groups before the first surgery might have been missed, which would potentially influence the study outcome. Nevertheless, with the matched-pair design of the study, this seems unlikely. In addition, as failure in terms of the need for reintervention has been defined as an outcome parameter, at least this parameter seems independent from preoperative knee function.

Concerning the conclusions of the present study, we observed a higher failure rate in cases where microfracturing had been applied before ACI. Because no other cartilage treatments were included in this study, it cannot be concluded if a higher failure rate after microfracturing is specific for the type of treatment or a general observation in patients who failed an initial treatment. This, however, is possible because all patients failed microfracturing as their primary treatment and presented with greater failure rates after ACI. Therefore, it could be concluded that these patients might have been predisposed to also fail ACI as a first-line treatment.

By excluding patients from our study who had been treated with any surgical treatment before ACI other than microfracture, total case numbers were reduced. This led to a more specific approach to analyze the questions raised above but makes statistically significant results more difficult to obtain and is further complicated by the relatively high standard deviations observed for the scoring systems of this study (IKDC, KOOS). Still,
similarly pronounced standard deviations have been reported by other studies. 23

In conclusion, this matched-pair analysis helps to clarify the controversy concerning the negative effect of previous microfracturing on subsequent revision ACI. Through specifically analyzing cases where microfracturing was the only treatment before ACI and comparing those with a matched-pair group that received ACI as a first-line treatment, we identified failed microfracturing as a risk factor for failure of subsequent ACI.

REFERENCES


Force Measurements in the Medial Meniscus Posterior Horn Attachment

Effects of Anterior Cruciate Ligament Removal

Keith L. Markolf,† PhD, Steven R. Jackson,‡ and David R. McAllister,§ MD

Investigation performed at Biomechanics Research Section, Department of Orthopaedic Surgery, David Geffen School of Medicine at UCLA, Los Angeles, California

Background: Tears of the medial meniscus posterior horn attachment (PHA) occur clinically, and an anterior cruciate ligament (ACL)-deficient knee may be more vulnerable to this injury.

Hypothesis: The PHA forces from applied knee loadings will increase after removal of the ACL.

Study Design: Controlled laboratory study.

Methods: A cap of bone containing the medial meniscus PHA was attached to a load cell that measured PHA tensile force. Posterior horn attachment forces were recorded before and after ACL removal during anteroposterior (AP) laxity testing at ±200 N and during passive knee extension tests with 5 N·m tibial torque and varus-valgus moment. Selected tests were also performed with 500 N joint load.

Results: For AP tests with no joint load, ACL removal increased laxity between 0° and 90° and increased PHA force generated by applied anterior tibial force between 30° and 90°. For AP tests with an intact ACL, application of joint load approximately doubled PHA forces. Anteroposterior testing of ACL-deficient knees was not possible with joint load because of bone cap failures from high PHA forces. Removal of the ACL during knee extension tests under joint load significantly increased PHA forces between 20° and 90° of flexion. For unloaded tests with applied tibial torque and varus-valgus moment, ACL removal had no significant effect on PHA forces.

Conclusion: Applied anterior tibial force and external tibial torque were loading modes that produced relatively high PHA forces, presumably by impingement of the medial femoral condyle against the medial meniscus posterior horn rim. Under joint load, an ACL-deficient knee was particularly susceptible to PHA injury from applied anterior tibial force.

Clinical Relevance: Because tensile forces developed in the PHA are also borne by meniscus tissue near the attachment site, loading mechanisms that produce high PHA forces could also produce complete or partial radial tears near the posterior horn, a relatively common clinical observation.

Keywords: knee biomechanics; medial meniscus

Meniscus tears are the most common injury to the knee, with medial meniscal tears occurring at approximately twice the rate of lateral meniscal tears. The most frequent sites for injury to the medial meniscus are near the posterior horn, where radial, horizontal, and cleavage plane tears are commonly observed. Recently, tears of the posterior horn attachment (PHA) of the medial meniscus to the tibial spine have been recognized as a distinct entity that produces radial extrusion of the meniscus and medial joint space narrowing with loss of articular cartilage. Posterior horn tears of the lateral meniscus are less common, and anterior horn tears of either meniscus are relatively infrequent. It is possible that integrity of the anterior cruciate ligament (ACL) could be an important factor related to the occurrence of meniscal tears. Studies have shown that ACL-deficient knees have a higher incidence of meniscus tears (specific locations not specified) and that ACL reconstruction appears to lower the incidence of these tears. However, it has not been shown that tears of the PHA are more common after ACL injury.

The biomechanical functions of the menisci have undergone extensive study, and their roles in absorbing energy and distributing contact forces over the cartilage of the tibial plateau are well documented. An intact meniscus performs this function by developing circumferential tensile