

Morphologic Properties of Cartilage Lesions in the Knee Arthroscopically Prepared by the Standard Curette Technique Are Inferior to Lesions Prepared by Specialized Chondrectomy Instruments

Adrian Blasiak,^{*} MD, PhD, Graeme P. Whyte,^{†‡§} MD, MSc, FRCSC, Adrian Matlak,^{*} MD, Roman Brzóska,^{||} MD, PhD, and Boguslaw Sadlik,^{*} MD, PhD
Investigation performed at Biological Joint Reconstruction Department, St. Luke's Hospital, Bielsko-Biala, Poland

Background: Cartilage lesion preparation is an important component to cartilage repair procedures, given the effect of prepared lesion morphology on the formation of durable and well-integrated repair tissue.

Purpose: To compare the quality of arthroscopic cartilage lesion debridement performed by (1) the standard curette (SC) technique and (2) specialized chondrectomy (CM) instruments, to provide technical guidance for optimization of cartilage lesion preparation in the setting of arthroscopic cartilage repair.

Study Design: Controlled laboratory study.

Methods: Articular cartilage lesions of standardized size (8 × 15 mm) were demarcated within the trochlea and femoral condyles of 20 human cadaver knee specimens. Orthopaedic surgeons performed arthroscopic lesion preparation using 2 techniques that consisted of SC preparation and preparation by CM instruments. A histologic comparative analysis was performed within each treatment group and between treatment groups to evaluate the morphology of prepared cartilage defects.

Results: The mean angle deviation from perpendicular of the cartilage wall at the front of the prepared cartilage lesions was significantly greater in the SC group versus the CM group ($29.8^\circ \pm 21.4^\circ$ vs $7.7^\circ \pm 7.6^\circ$, $P < .001$). In lesions prepared via the SC technique, the cartilage walls at the front of the prepared lesions were significantly less perpendicular than the cartilage walls at the rear of the lesions ($29.8^\circ \pm 21.4^\circ$ vs $11.0^\circ \pm 10.3^\circ$, $P < .001$), whereas lesions prepared by the CM technique demonstrated comparable verticality of surrounding cartilage walls at the front and rear aspects of the lesions ($7.7^\circ \pm 7.6^\circ$ vs $9.4^\circ \pm 12.3^\circ$, $P = .827$). Depth of lesion debridement was accomplished to the target level by the CM technique in 86% of prepared lesions, compared with 34% of lesions in the SC group. The prepared cartilage wall profile was characterized as the most ideal morphology in 55% of prepared lesions in the CM group, as opposed to 10% in the SC group.

Conclusion: Arthroscopic cartilage lesion preparation with SC instruments results in superior perpendicularity of surrounding cartilage walls to subchondral bone and greater consistency of debrided lesion depth, as compared with the standard debridement technique with curettes.

Clinical Relevance: Arthroscopic preparation using standard curette technique leads to suboptimal morphologic characteristics of prepared lesions that likely affect the quality of repair tissue, compared to preparation using specialized chondrectomy instruments.

Keywords: cartilage debridement; cartilage repair; cartilage lesion; knee arthroscopy; articular cartilage; cartilage histology

Injury to articular cartilage within the knee joint is often associated with pain and functional decline, and the limited capacity for healing of articular cartilage has led to the development of numerous strategies to surgically treat

such lesions. Irrespective of the method used to repair articular cartilage, providing the optimal environment for cartilage tissue to regenerate and integrate is considered an important component of the procedure and is dependent on appropriate preparation of the cartilage lesion.²² To restore articular cartilage, an array of procedures have been developed that depend on appropriately prepared lesions, from traditional marrow stimulation techniques (such as microfracture)^{10,26} to more advanced methods of

cell-based repair, such as autologous chondrocyte implantation and scaffold-associated mesenchymal stem cells sourced from bone marrow aspirate concentrate.^{9,11}

When preparing lesions in anticipation of cartilage repair, the surrounding cartilage walls should be sharply debrided to create walls perpendicular to the subchondral bone, and the base of the lesion is prepared in such a fashion that minimizes violation of the subchondral bone. Injury to subchondral bony architecture may lead to advancement of the subchondral plate and promote intralesional osteophyte formation, potentially having a great impact on the long-term outcomes of cartilage repair procedures.²⁰ While open methods of cartilage lesion preparation typically provide excellent visualization and complete access about the defect periphery, limitations of access during arthroscopic procedures may result in suboptimal lesion preparation with the standard curette (SC) technique. As techniques progress to minimally invasive forms of cartilage repair, it should be ensured that arthroscopic methods of cartilage lesion debridement consistently lead to prepared defects of appropriate morphology.

The purpose of this study was to compare the quality of arthroscopic cartilage lesion debridement performed by (1) the SC technique and (2) specialized chondrectomy (CM) instruments, to provide technical guidance for optimization of cartilage lesion preparation in the setting of arthroscopic cartilage repair. We hypothesized that preparing cartilage lesions with specialized instruments would result in superior verticality of surrounding cartilage walls and more accurate depth of debridement as compared with lesions prepared with the SC technique.

METHODS

Twenty fresh-frozen skeletally mature human knee specimens were obtained from the United Tissue Network. Specimens were secured to an apparatus and positioned for standard knee arthroscopy. Specimens were fixed at the distal femur, which was positioned parallel to the floor with the knee joint at 90° of flexion. The knee joint was free to mobilize through a full range of motion. Anterolateral and anteromedial portals were created, and standardized elliptical-shaped areas of cartilage (8 × 15 mm) were templated and marked arthroscopically at the medial femoral condyle, lateral femoral condyle, medial trochlea, and lateral trochlea with a radiofrequency electrode by a supervising orthopaedic surgeon specialized in arthroscopic cartilage repair procedures of the knee.

Forty attending orthopaedic surgeons participated in the study. All surgeons were experienced in knee arthroscopy and performed this procedure routinely in practice. Two surgeons were assigned to each cadaver specimen,

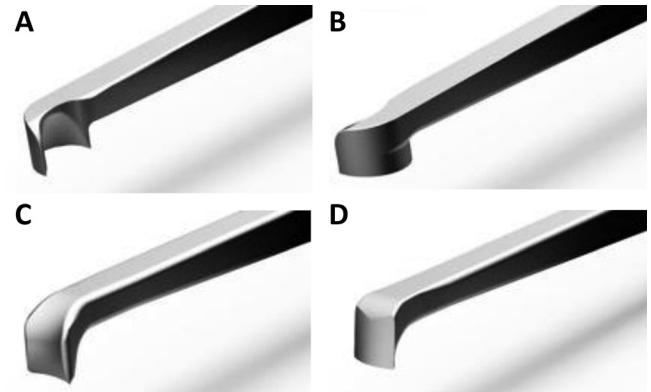


Figure 1. Chondrectome instruments used for cartilage defect preparation: (A) crescent shaped left cutting, (B) crescent shaped right cutting, (C) plano-concave forward cutting, (D) plano-concave backward cutting.

and each participant alternated between roles of primary operator and assistant. Each templated lesion was assigned to 1 surgeon, with each surgeon responsible for 1 condylar lesion and 1 trochlear lesion.

Procedural Protocol

Each surgeon prepared 2 cartilage defects. One defect was prepared per the SC technique, with instruments that consisted of a cup curette (Arthrex); a 5.4-mm open ring curette, 1 side cutting (Arthrex); and a 5.4-mm open ring curette, both sides cutting (Arthrex). The other defect was prepared with instruments from a CM set (ATMED) (Figure 1). After the preparation of each lesion, the front and rear aspects of the cartilage defect were marked by the participant arthroscopically.

Surgeons used the anteromedial and anterolateral portals for access to the templated articular cartilage areas. Surgeons were allowed to create additional portals for access as needed, and they were free to flex and extend the knee specimens as desired. The participants were instructed to create a full-thickness cartilage lesion bordered by the templated area, surrounded by uninjured cartilage walls perpendicular to the subchondral plate (Figure 2). They were further instructed to remove the calcified cartilage layer at the base of the defect without disrupting the subchondral plate.

Histologic Preparation and Examination

Osteochondral blocks encompassing each prepared cartilage lesion were harvested with an oscillating saw to

[§]Address correspondence to Graeme P. Whyte, MD, MSc, FRCSC, New York Presbyterian Hospital/Queens, 56-45 Main Street, New York, NY 11355, USA (email: gphwhyte@gmail.com).

^{*}Biological Joint Reconstruction Department, St Luke's Hospital, Bielsko-Biala, Poland.

[†]Weill Medical College, Cornell University, New York Presbyterian Hospital/Queens, New York, NY, USA.

[‡]Orthopaedic Arthroscopic Surgery International Bioresearch Foundation, Milan, Italy.

^{||}Department of Upper Limb Surgery, St Luke's Hospital, Bielsko-Biala, Poland.

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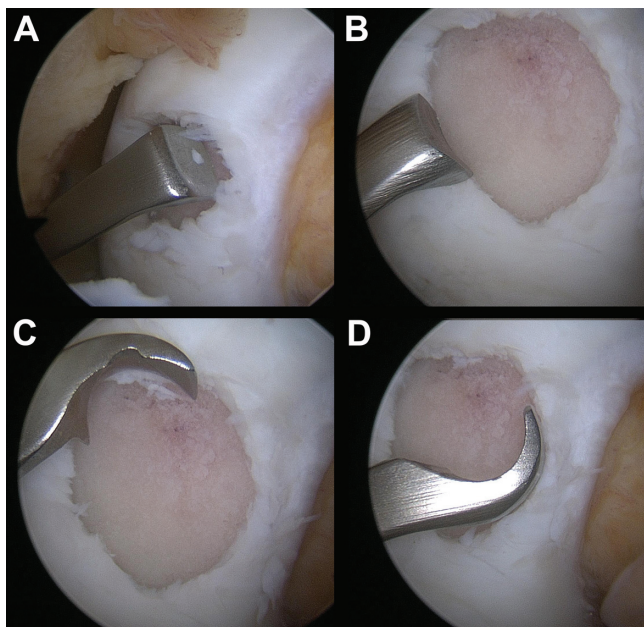


Figure 2. Cartilage lesion preparation of a defect located at the medial femoral trochlea in a right knee, arthroscopic view from the anterolateral portal. Preparation about the periphery of the lesion depicted with (A) the plano-concave backward-cutting chondrectome, (B) the plano-concave forward-cutting chondrectome, (C) the crescent-shaped right-cutting chondrectome, and (D) the crescent-shaped left-cutting chondrectome.

a depth of 2 cm, with a 1-cm peripheral margin about the defect. Each specimen was fixed in 10% buffered formalin for 72 hours and then decalcified for 4 weeks. Each prepared lesion was embedded in paraffin and then cut longitudinally through the center of the specimen. Two to 6 serial sections were obtained for each sample, cut to a thickness of 0.5 μ m, and then stained with hematoxylin and eosin. Each sample depicted the longitudinal plane of the lesion, including the cartilage walls at the front and rear aspects of the defect and the subchondral bone at the base. A high-resolution scanner imaged each section. For each prepared defect, a single section demonstrating the best histologic quality was chosen for analysis (Figure 3). Sections determined to be inadequate for histologic evaluation owing to damage during harvesting or preparation were excluded from the analysis. Both samples from each surgeon were excluded in the case of damaged sections, to maintain paired analysis for each participant. Histologic analysis was performed according to the criteria of Drobnic et al⁵ (Table 1).

Statistical Analysis

Data analysis was performed with SPSS software (v 20.0; IBM Corp). Normality of continuous variables was examined with the Shapiro-Wilks test and quantile-quantile plots. Continuous variables are expressed as mean \pm SD.

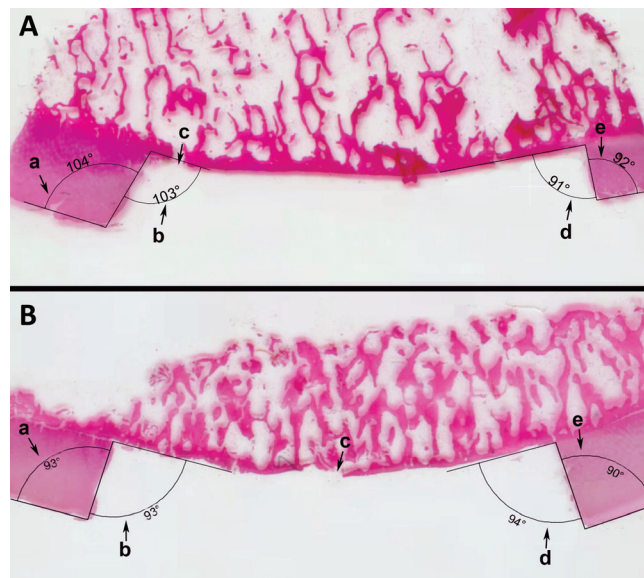


Figure 3. Histologic section from cartilage lesion prepared arthroscopically by method of (A) standard curette technique and (B) chondrectome technique: measurements for rear outer angle (a) and rear inner angle (b), bone sinusoids access (c), and measurements for front inner angle (d) and front outer angle (e).

The absolute value of angle deviation from perpendicular was used for comparative data analysis. Analysis of variance was used to compare mean angle measurements and to examine mean angle differences within treatment groups among locations of lesion preparation, with post hoc Tukey correction performed for multiple comparisons where appropriate. Fisher exact test was used to examine frequencies of qualitative categorizations between treatment groups. One-sample chi-square testing was used to examine frequencies of qualitative categorizations within treatment groups.

RESULTS

Fifty-eight specimens were analyzed from 80 prepared samples. Eleven specimens were excluded from the SC group and 11 from the CM group. Mean front outer angle measurement was significantly greater in the SC group versus the CM group ($26.5^\circ \pm 17.3^\circ$ vs $7.4^\circ \pm 7.5^\circ$, $P < .001$). Mean front inner angle was significantly greater in the SC group ($29.8^\circ \pm 21.4^\circ$ vs $7.7^\circ \pm 7.6^\circ$, $P < .001$). Mean rear outer angle was $10.6^\circ \pm 8.5^\circ$ for the SC group and $7.4^\circ \pm 9.5^\circ$ for the CM group ($P = .187$). Mean rear inner angle was $11.0^\circ \pm 10.3^\circ$ for the SC group and $9.4^\circ \pm 12.3^\circ$ for the CM group ($P = .582$). Within-group analysis demonstrated significant differences in mean angle measurements about the prepared lesion in the SC group ($P < .001$) and no location-dependent differences in mean angle measurements in the CM group ($P = .827$). Histologic analysis is completely detailed in Table 2.

TABLE 1
Evaluation Criteria for the Histologic Examination of Prepared Cartilage Lesions^a

Criterion	Description	Measurement Category
Lesion angle	Angle analysis was applied to the following: (1) outer angles—between surrounding cartilage surface and lesion wall on the front and rear aspects of each sample; (2) inner angles—between the lesion wall and lesion base on the front and rear aspects of each sample.	Degrees
Surrounding cartilage	Up to 2 mm of the intact cartilage on each side of the rim of the debrided lesion was analyzed with a semiquantitative scale.	Intact Shallow fissure(s) (<20% depth) Partial-thickness injury (20%-80% depth) Full-thickness injury (>80%)
Cartilage wall profile	The cartilage wall at both sides of the lesion was analyzed with a semiquantitative scale for any disturbances.	Straight, flat Superficial disturbances <1 mm Concave Convex
Debrided lesion depth	Each histologic slide was analyzed by a stereological cycloid grid incorporated into a microscope lens at 100× magnification. The depth level at each intersection with the gridline was determined and the corresponding percentages calculated.	Deep zone Calcified zone Subchondral end plate Deep bone (sinusoids)
Bone sinusoids access	The openings to the bone sinusoids were counted.	Number of openings
Bone surface profile	Bone surface profile	Straight, flat Superficial disturbances <1 mm Crater (central part deeper) Bump (peripheral part deeper)

^aAdapted from Drobnič et al.⁵

There were significant differences in the cartilage wall profile between treatment groups ($P = .001$), with 55% of lesions classified as the most ideal ("straight, flat") and 3% as the least ideal ("bump") in the CM group, compared with 10% and 24% in the SC group, respectively. There were significant differences in debrided lesion depth between groups ($P < .001$), with 86% of lesions prepared to the goal depth ("subchondral end plate") in the CM group, compared with 34% in the SC group. There were no significant differences identified between groups with regard to evaluation of surrounding cartilage ($P = .602$), bone sinusoid access ($P = .497$), and bone surface profile ($P = .178$).

Within-group analysis of lesion morphology in the CM group indicated that the greatest proportion of samples were categorized as the most ideal classification with respect to all histologic assessments of lesion morphology (Table 2). Analysis of prepared lesion morphology in the SC group showed no differences in the assessment of surrounding cartilage ($P = .185$), debrided lesion depth ($P = .279$), or bone surface profile ($P = .413$), while there were significant differences in cartilage wall profile ($P = .007$) and bone sinusoid access ($P = .004$).

Within-group analysis of cartilage wall verticality about the prepared lesions demonstrated that the front outer and front inner cartilage walls were significantly less vertical than the rear outer wall in the SC group. There were no location-dependent differences in mean cartilage wall verticality identified in the lesions prepared by the CM technique (Table 3).

DISCUSSION

In the current study, arthroscopically prepared cartilage lesions with CM instruments achieved superior verticality of cartilage walls at the front of the lesions as compared with the SC technique. The CM preparation technique resulted in comparable verticality of surrounding cartilage walls at the front and rear aspects of the lesions, whereas the SC preparation achieved inferior verticality at the front aspect of the lesions compared with the rear. Furthermore, the cartilage wall profile was characterized as the most ideal ("straight, flat") in 55% of the CM group, compared with only 10% in the SC group. The target depth of debridement was achieved in 86% of CM preparations, whereas there was inconsistent depth of debridement achieved with the SC technique, with 34% of these preparations performed to the target depth.

The technique of open chondrectomy and debridement of the articular cartilage was described in 1946 by Magnusson.¹⁸ Since that time, there have been advancements in these techniques to optimize the restoration of durable repair tissue. Steadman et al²⁵ described guidelines consisting of removing damaged cartilaginous tissue, creating peripheral cartilage walls perpendicular to the subchondral bone, and removing the calcified cartilage layer without damaging the subchondral bone. Rudd et al²³ demonstrated that cartilage walls surrounding prepared cartilage lesions that lack verticality lead to degeneration of the remaining partial-thickness fragment and subsequently to lesion

TABLE 2
Comparison of Histologic Findings of Cartilage Lesions
Arthroscopically Prepared by the Standard Curette
Technique and the Chondrectome Technique^a

	Preparation		P Value
	Standard Curette (n = 29)	Chondrectome (n = 29)	
Location of preparation, angle ^b			
Rear outer	10.6 ± 8.5	7.4 ± 9.5	.187 ^c
Rear inner	11.0 ± 10.3	9.4 ± 12.3	.582 ^c
Front outer	26.5 ± 17.3	7.4 ± 7.5	<.001 ^{c,d}
Front inner	29.8 ± 21.4	7.7 ± 7.6	<.001 ^{c,d}
P value ^e	<.001 ^d	.827	
Surrounding cartilage			.602 ^f
Intact	48	62	
Solitary clefts	21	17	
Partial-thickness lesion	31	21	
Full-thickness lesion	0	0	
P value ^g	.185	.004 ^d	
Cartilage wall profile			.001 ^{d,f}
Straight, flat	10	55	
Superficial disturbances	52	31	
Crater	14	10	
Bump	24	3	
P value ^g	.007 ^d	<.001 ^d	
Debrided lesion depth			<.001 ^d
Deep zone	10	0	
Calcified zone	28	7	
Subchondral end plate	34	86	
Deep bone	28	7	
P value ^g	.279	<.001 ^d	
Bone sinusoid access			.497 ^f
None	62	69	
Minor	24	28	
Severe	14	3	
P value ^g	.004 ^d	<.001 ^d	
Bone surface profile			.178 ^f
Straight, flat	38	66	
Superficial disturbances	21	7	
Crater	24	14	
Bump	17	14	
P value ^g	.413	<.001 ^d	

^aValues are presented as mean ± SD or percentage.

^bAngle reported as absolute deviation from 90°.

^cAnalysis of variance used to examine differences in mean angles between treatment groups.

^dStatistically significant, $P < .05$.

^eAnalysis of variance used to examine mean angle differences within treatment groups among locations of lesion preparation.

^fFisher exact test used to examine frequencies between treatment groups.

^gOne-sample chi-square test used to examine frequencies within treatment groups.

enlargement. The findings regarding inconsistent verticality of prepared cartilage walls with SC debridement versus walls prepared by more specialized instruments are of clinical concern, given the potential effect on the quality of regenerated cartilage tissue. While open lesion preparation with curettes allows for complete lesion visualization that will assist with consistent preparation of surrounding cartilage walls that are perpendicular to the subchondral bone, there is greater difficulty during arthroscopic preparation in positioning the curette cutting edge appropriately about

TABLE 3
Within-Group Comparisons of Cartilage Wall
Verticality About the Prepared Cartilage Defects:
Standard Curette vs Chondrectome Technique^a

Comparison	Standard Curette		Chondrectome	
	Mean Angle Difference	P Value	Mean Angle Difference	P Value
RO-RI	-14.7	.136	-2.0	.851
RO-FO	-30.1	<.001 ^b	-0.0	>.999
RO-FI	-29.8	<.001 ^b	-0.3	>.999
RI-FO	-15.5	.104	2.0	.858
RI-FI	-15.1	.117	1.7	.899
FO-FI	0.3	>.999	-0.2	>.999

^aAs measured by angle deviation from perpendicular. FI, front inner; FO, front outer; RI, rear inner; RO, rear outer.

^bStatistically significant, $P < .05$.

the lesion because trajectory options are limited, and there is risk of creating iatrogenic partial-thickness lesions about the lesion that affect previously healthy cartilage.

Removing the layer of calcified cartilage at the base of the defect in preparation for cartilage repair has been recommended to increase the volume of regenerated reparative cartilage tissue and to improve the strength of integration with subchondral bone.⁸ Depth of lesion debridement with the SC technique resulted in inconsistent depth of debridement, whereas in the CM group, the majority of lesions (86%) were prepared to the target depth of subchondral bone after removal of the calcified cartilage layer. A notable proportion of lesions debrided with the SC technique (28%) were debrided to the level of deep bone, which may increase the risk of developing pathologic changes in the architecture of the subchondral plate after performance of cartilage repair procedures, such as advancement of the subchondral plate or intralesional osteophyte formation. While violation of the subchondral plate with SC for lesion preparation use was not a frequent occurrence in work published by Mika et al,¹⁹ the target depth of debridement in that study was more superficial, as the calcified cartilage layer was left intact during preparation. Changes within subchondral bone may precede alterations in adjacent articular cartilage, and preparation of lesions to an adequate depth without significant injury to the subchondral end plate are important considerations to maximize the content of type II collagen within the repair tissue and potentially restore the calcified cartilage and tidemark layers.^{3,14} Removal of the calcified cartilage layer during lesion preparation improves the quality of restored cartilage as well as the attachment of repair tissue.⁸

Procedures that restore durable cartilage repair tissue continue to be developed with varying degrees of success. The anatomy and physiology of the osteochondral unit are complex, and the morphology of the entire structure should be considered during repair of articular cartilage defects, even without apparent involvement of subchondral

bone, as the subchondral bone and overlying cartilage form a functional unit that is metabolically active and constantly responds to surrounding mechanical stresses and metabolic factors.^{1,6,17,21} Degenerative injury to articular cartilage is associated with pathologic changes to subchondral bone,^{2,15,16} and attempted repair of articular cartilage without a healthy supporting subchondral bone structure is not likely to be successful.¹² These considerations highlight the importance of meticulous cartilage lesion preparation prior to performing repair procedures in order to optimize the microenvironment for durable reparative tissue to regenerate and also to properly integrate into surrounding structures.

Drobnic et al⁵ reported that open chondrectomy leads to greater precision of lesion preparation with commonly used tools, and they recommended using a scalpel blade to cut the lesion margins to create vertical walls peripherally and the SC technique to prepare the bony lesion base. This highlights an important disadvantage of currently preferred instruments for arthroscopic cartilage lesion preparation, such as ring curettes. The current study showed that while arthroscopic lesion preparation with curettes results in poor verticality of cartilage walls at the front of the lesion, CM instruments specifically designed for arthroscopic lesion preparation were capable of creating perpendicular walls peripherally, irrespective of location. Furthermore, Drobnic et al⁵ used a combination of human and equine specimens, and there were differences in the calcified cartilage and tidemark layers on the equine specimens that made determination of debridement depth difficult.

There are several limitations to this study. Cadaver specimens that encompass the entire lower extremity would be an improved method to simulate the arthroscopic procedure, although the current methodology is preferable to studies that rely on animal models. It is notable that all specimens were of human origin—this is an important advantage over numerous experimental models previously described.^{5,19} There can be great variability among animal species in the thickness of layers within the osteochondral unit and among the constituent layers; the metabolic interaction between layers also varies.^{1,4,13} Of 80 histologic sections, 22 samples were not included in the histologic analysis, because of damage during the harvesting process or during preparation, decalcification, or staining. Examination of samples was in the longitudinal plane and did not include analysis of the transverse axis. Additional preparation of samples in the transverse plane was not feasible after the specimens had been sliced longitudinally. The longitudinal plane used for histologic analysis was considered the most important to study because of the greater difficulty expected with arthroscopic lesion preparation at the front aspect of the lesions, given the impairments to visualization and access for instruments.

Given the rapid progression of cartilage repair technology that is now used in the setting of minimally invasive surgical approaches such as arthroscopy,^{7,24,27} there should be specific focus on the capabilities of commonly used techniques and instrumentation to properly prepare cartilage lesions during this surgical approach. Ensuring

consistent perpendicularity of surrounding cartilage walls about prepared lesions and reproducibly preparing the defect base to the desired depth are crucial components of cartilage lesion preparation, and commonly used curettes have not been shown to be capable of adequately performing these tasks under arthroscopic conditions.

CONCLUSION

Arthroscopic cartilage debridement and lesion preparation with CM instruments result in superior perpendicularity of surrounding cartilage walls to subchondral bone and greater consistency of debrided lesion depth when compared with the standard debridement technique with curettes.

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