Original Article

Arthroscopic Suture-Saucerization of Discoid Meniscus Allows Volume Conservation but Does Not Fully Restore Coverage

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Purpose: The purpose of this study was to quantify the effect of meniscoplasty suture-saucerization on volume and surface coverage of lateral discoid menisci. **Methods:** This retrospective study included all consecutive 10 patients treated between 2014 and 2019 who had magnetic resonance imaging before and after surgery and 15 controls. The MITK 3M3 semiautomatic software was used to segment the meniscus and cartilage before and after surgery to measure the percentage of meniscus coverage on the tibial cartilage. Results are compared to control patients without knee pathology matched on sex and age with Student *t* test. **Results:** Discoid meniscus surface and volume before surgery were respectively 597 mm^2 (range, 550-887 mm^2) and 2,822 mm^3 (1,571-3,407 mm^3), representing 74.5% (56%-89%) of the tibial cartilage surface. After surgery, it decreased to 422 mm^2 (229-569 mm^2) and 1,235 mm^3 (680-1,738 mm^3), leading to 45.7% (22.5%-68.6%) coverage. In the control group, median surface was 457 mm^2 (314-641 mm^2), volume was 1,321 mm^3 (641-2,240 mm^3), and tibial coverage was 55% (41%-77%). Altogether, meniscus volume after surgery was similar to normal, while coverage was significantly lower than controls ($P = .04$). **Conclusions:** Meniscoplasty suture-saucerization procedure may allow meniscus sparing and restauration of a similar to normal meniscus volume. Meniscus surface and coverage are diminished compared to controls. Both surface and volume normalization is usually not achievable without decreasing the thickness of the rather thick discoid meniscus. **Clinical Relevance:** Both surface and volume normalization is usually not achievable without decreasing the thickness of thick discoid menisci.

Discoid meniscus is a rare congenital anomaly of the knee. Prevalence varies from 26.8 per million in the Black ethnicity to 60.1 per million in the Hispanic population.[1] From 10% to 69% of patients have bilateral discoid meniscus[2-4] depending on the way it is investigated. Usually asymptomatic, discoid meniscus may be revealed by pain or protrusion, leading to discomfort. Diagnosis is confirmed by magnetic resonance imaging (MRI). The major interest in MRI was confirmed by Ahn et al.,[5] who published a preoperative classification based on the meniscus shift. Ahn et al.[6] also proposed to class them into 3 types based on the per-operative findings.

Historically, total menisectomy was performed to treat this congenital defect. It was later on revealed that meniscectomy, even partial, led to early osteoarthritis.[7-9] Arthroscopic meniscus suture-saucerization, a meniscoplasty method, emerged in the 1990s.[10-12] There is commonly a meniscus disinsertion associated with discoid meniscus in children that usually requires

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Table 1. Control Group Main Characteristics

Patient No.	Age, y	Sex	Meniscus Surface (mm^2)	Cartilage Surface (mm^2)	Coverage (%)	Meniscus Volume (mm^3)
1	11	M	446	740	60	1,322
2	7	M	457	831	55	1,367
3	13	M	487	1,050	46	1,321
4	13	M	528	814	65	1,663
5	16	F	349	694	50	1,122
6	11	M	474	732	65	1,597
7	11	M	400	768	52	1,362
8	14	F	480	871	55	1,232
9	10	F	612	791	77	2,169
10	15	M	641	1,040	62	2,240
11	7	F	344	735	47	676
12	11	F	464	686	68	1,295
13	4	M	314	771	41	641
14	8	F	360	740	49	1,178
15	7	M	315	757	42	792
Median (min-max)			457 (314-641)	768 (686-1,050)	55 (41-77)	1,321 (641-2,240)
Mean ± SD			444.7 ± 100	801.3 ± 110	55.6 ± 10.4	1,332 ± 462

both a suture and a meniscoplasty. The treatment consists of diminishing lateral tibial cartilage coverage by the discoid meniscus to diminish constraints between the femoral condyle and the diseased meniscus that may lead to meniscus disinsertion.

Some studies were performed to measure meniscus in normal or pathologic conditions.[13-15] The purpose of this study was to quantify the effect of meniscoplasty suture-saucerization on volume and surface coverage of lateral discoid menisci.

Methods

Population

In this retrospective study, we included all patients who underwent discoid meniscus treatment with MRI available before and after surgery between 2014 and 2019. Among 16 patients with symptomatic lateral discoid meniscus, 7 were excluded due to the absence of pre- or postsurgical MRI. There was 5 girls and 4 boys among the 9 patients (10 knees) selected. They underwent surgery between August 2014 and July 2019. Mean age at surgery was 9 years (range, 5-12 years). Nine knees out of 10 had a symptomatic meniscus disinsertion. Mean follow-up was 40 months. Eight knees had no shift using the Ahn MRI classification. One had a “central shift” lesion and 1 a “postero-central shift.” All discoid menisci were complete (type 1) using the Watanabee classification. Mean symptom duration before surgery was 21.6 months. Our pathologic group was compared to a control group of 15 patients (15 knees; Table 1) without particular medical history, with a similar age and sex distribution who had MRI performed due to a minor trauma. No meniscus, ligamental, or osteochondral lesions were detected.

Surgical Procedure

The surgical procedure was the same for all patients: arthroscopy under general anesthesia and pneumatic tourniquet by 2 experienced operators. First exploration allowed determining the Ahn per-operative disease stage,[6] classified as type 1 with anterior menisco-capsular disinsertion, type 2 with posterior horn disinsertion, and type 3 with a posterolateral lesion without a lesion of the menisco-capsular junction. Meniscoplasty was performed using a basket clamp and a motorized shaver (Fig 1A). Partial saucerization and meniscal suture, followed by additional saucerization if needed, were performed with an emphasis on removing as little meniscus as possible. Meniscus suture was realized using the “out-in” technique (meniscus Mender; Smith and Nephew), “in-out” technique (Acufex; Smith and Nephew), or “all-inside” technique (Fast-fix; Smith and Nephew) depending on whether the meniscus disinsertion was anterior or posterior.

MRI

The 1.5 T MRI was performed with 10° of knee dorsal flexion for both the pathologic and control groups before surgery and at least 1 year after surgery. Informatic analysis was performed using coronal slices in fat-saturated T2 sequences using the easy to use and reliable MITK 3M3 software.[16]

Meniscus Segmentation

The MITK 3M3 semiautomatic software allows one to measure a surface and volume of structures by segmentation (lateral tibial cartilage and lateral meniscus). Manual highlighting of structures of interest was needed on 10 to 15 slices (Fig 1C), allowing the calculation of cartilage coverage, surface, and volume (Fig 1B). To quantify inter- and intraobserver (orthopaedic surgeon) reproducibility, a second set of

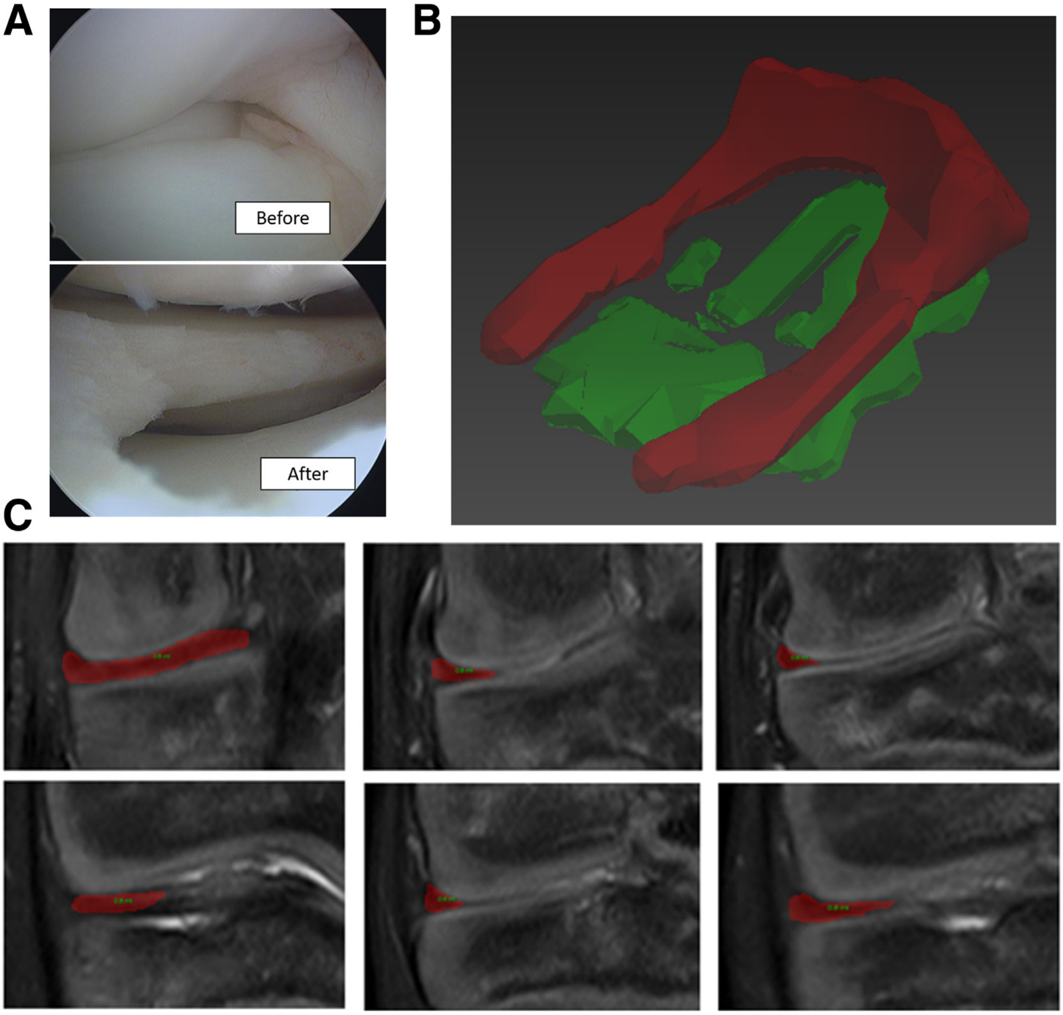

Fig 1. Arthroscopic view of anterior meniscoplasty suture and meniscus segmentation on magnetic resonance imaging (MRI). (A) Meniscus before and after saucerization (before suture). (B) Three-dimensional aspect of saucerized discoid meniscus (red) on its tibial cartilage (green) using MITK 3M3 software. (C) Meniscus segmentation on coronal MRI.

measurements was performed 1 year after the first one in the pathologic group and quantified using the κ coefficient.

Statistical Analysis

Results are described as medians with the range of observed values. Measures may also be presented as mean ± standard deviation. Meniscus surface, volume, and coverage are considered normally distributed (*F* test $P > .05$) with similar variance between the independent controls and the pathologic group. Student *t* test was used to compare surface, volume, and coverage of control and pathologic meniscus.

Results

Postsurgical MRI was performed at a mean of 22 months (12-34 months) after surgery as part of the routine postsurgical practice in our institution. One patient required another surgical intervention for a protrusion of the saucerized discoid meniscus 63 months after the initial surgery. This protrusion was treated by simple reduction and suture without meniscoplasty. Pain was evaluated at a mean follow-up of 40 months; 3 of 10 knees were reported as painful after surgery.

Median discoid meniscus surface before surgery (Table 2) was 597 mm^2 (550-887 mm^2). Median cartilage surface was 879 mm^2 (716-1,184 mm^2). Median presurgical cartilage coverage was 74.5%. Postsurgical median surface of the treated meniscus was 422 mm^2 (229-569 mm^2). The mean coverage after surgery was 45.7% (22.5%-68.6%). Results in terms of net decrease in coverage for each patient are presented in Figure 2. The median external meniscal surface in the control group was 457 mm^2 (314-641 mm^2) (Table 1). Of note, there was no correlation between tibial surface and age or sex in our cohort. The control mean tibial cartilage surface was 768 mm^2 (686-1,050 mm^2),

Table 2. Patient With Discoid Meniscus Characteristics Before and After Surgery

				Before Surgery				After Surgery			
Patient No.	Age, y	Sex	Shift as Described by Ahn et al.[5]	Meniscus Surface (mm^2)	Cartilage Surface (mm^2)	Coverage (%)	Meniscus Volume (mm^3)	Meniscus Surface (mm^2)	Coverage (%)	Meniscus Volume (mm^3)	Net Decrease in Coverage (%)
1	5	F	No	618	829	74.5	2,923	569	68.6	1,398	5.9
2	12	M	No	584	905	64.5	3,087	497	54.9	1,311	9.6
3	9	F	Central	550	1,124	48.9*	1,678	488	43.4	1,007	5.5
4	12	F	No	675	952	70.9	2,932	566	59.5	1,738	11.4
5	11	M	No	887	1,184	74.9	3,407	266	22.5	1,159	52.4
6	9	M	No	610	821	74.3	2,968	282	34.3	680	40
6'	9	M	No	561	716	78.4	1,608	229	32	1,082	46.4
7	9	M	No	760	853	89	2,720	356	54.3	1,342	34.7
8	8	F	No	563	734	76.7	2,329	261	35.6	1,053	41.1
9	10	F	Postero-central	567	1,017	56*	1,571	488	48	1,313	8
Median (min-max)				597 (550-887)	879 (716-1,184)	74.5 (56-89)	2,822 (1,571-3,407)	422 (229-569)	45.7 (22.5-68.6)	1,235 (680-1,738)	23.05 (5.5-2.4)
Mean ± SD				637.5 ± 108.9	913.5 ± 156.5	70.8 ± 11.6	2,522 ± 680	400 ± 134.7	45.3 ± 14.3	1,208 ± 282	25.5 ± 19

*Denotes patients with a disinserted and luxation during MRI ("shift" as described by Ahn et al.[5]).

corresponding to a median 55% (41%-77%) coverage. The median discoid meniscus volume before surgery was 2,822 mm^3 (1,571-3,407 mm^3) and 1,235 mm^3 (680-1,738 mm^3) after surgery. In the control group, the median meniscal volume was 1,321 mm^3 (641-2,240 mm^3).

Patients after surgery had a rather similar meniscal volume ($P = .45$) compared to controls. On the contrary, patients had a lower meniscal coverage than controls ($P = .04$).

Intra- and interobserver correlations on surface and volume were considered weak to moderate with a mean correlation of 0.67 and 0.54, respectively (Table 3). Detailed results of intra- and interobserver measurements are depicted in Supplementary Tables 1 and 2.

Discussion

Median meniscus coverage was 74.5% before surgery and 45.7% after surgery vs 55% in the control group, meaning that the meniscus coverage was significantly lower than control after treatment ($P < .04$). Median meniscus volume was 2,835 mm^3 before surgery and 1,235 mm^3 after surgery, a value similar to the one obtained vs 1,321 mm^3 in the control group. Meniscus conservation seems therefore generally achieved.

More generally, our findings show that the saucerization suture may lead to relatively variable outcomes in terms of meniscal coverage and partially in terms of volume. Postsurgical meniscal volume reflects meniscal preservation. After surgery, meniscus volume tends to be rather similar to the control group, whereas coverage tends to be lower. This may be explained by the fact that saucerization-suture consists of removing the medial part of the meniscus while keeping its lateral thickness constant. Discoid meniscus is thicker than normal ones, and both normal surface and volume may not be achievable without decreasing meniscus thickness. Decreasing meniscus thickness is, however, not advised in the peripheral part of the meniscus.

Whether we should aim at achieving a similar-to-control volume after surgery or a similar surface coverage is still an open and particularly interesting question. The thick meniscus left after surgery may evolve with time, growth, and pressure on it. It is still unknown whether it may, for example, become thinner and similar to normal with time in terms of surface coverage and shape.

Limited work has been published on meniscus segmentation applied to discoid meniscus up to now, with even less on discoid meniscus.[14,15] These studies rather explore normal adult meniscus[14] or the effect of osteoarthritis.[17,18] In these studies, meniscus coverage was 58.6%, quite similar to the one from our control group and in line with expected meniscus growth in children.[19] Two studies were focused on the evaluation of discoid

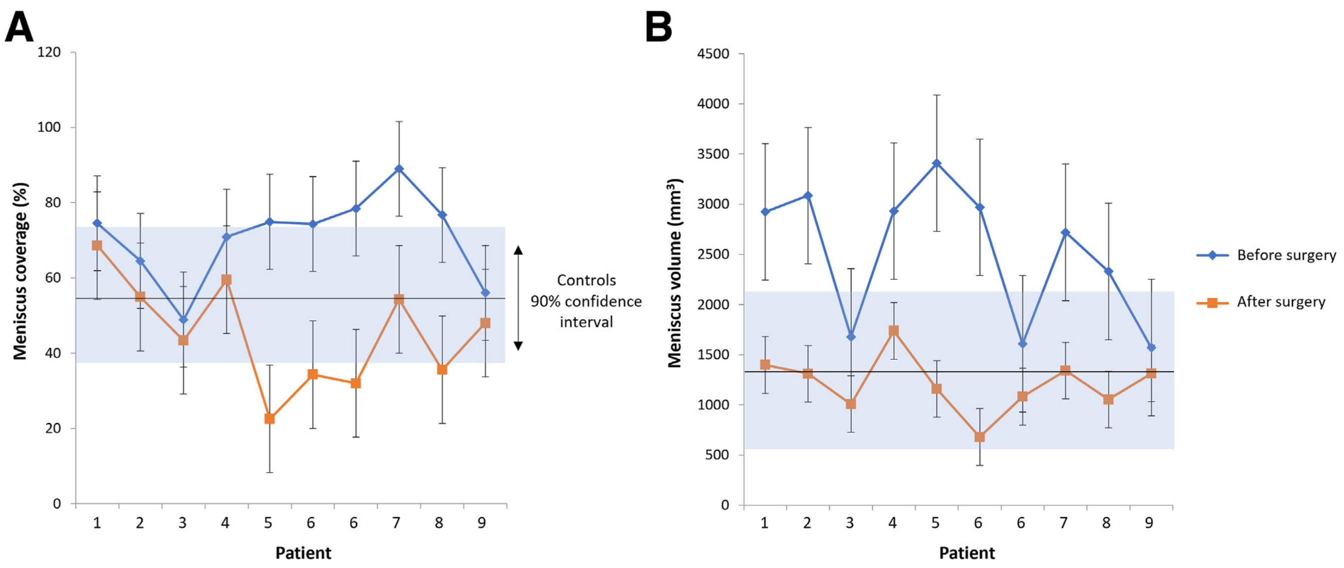

Fig 2. Effect of surgery on meniscus coverage and volume. (A) Meniscus coverage and (B) meniscus volume. Black line represents the mean value of controls, and blue zone represents the 90% confidence interval (±1.65 SD).

meniscus on MRI. Mayer-Wagner et al.[13] explored the meniscus length and thickness measurement on sagittal slices before and after surgery. They observed a 42% diminishment in length, mostly at the meniscus center. Wasser et al.[20] performed only width and height measurements on coronal slices of the anterior, median, and posterior horn of the saucerized meniscus on post-surgical MRI to confirm that these results were satisfying compared to the previously published literature. Our meniscoplasty results also seems satisfying, but it is difficult to directly compare surface and volume measurements by informatic segmentation to direct length, width, or thickness measurements on a few slices. Measuring total meniscus surface, coverage, and volume seems a more reliable, less biased, and more relevant measure of residual meniscus.

This study allowed us to obtain objective data on the effect of surgery in this pathology. Most long-term studies achieve good clinical results in children, although radiologic results are discussed more (premature osteoarthritis and potential diminishment of meniscus volume).[21,22] The predictive value of these radiologic signs on future functional outcome remains to be determined. Cartilage segmentation had a good inter- and intraobserver reproducibility (0.78 and 0.87, respectively), while meniscus had a weak to moderate reproducibility (ranging from 0.4 to 0.78). Precise meniscus limits are not always easy to distinguish (Supplementary Fig 1), particularly in most extremes slices (anterior or posterior) and when there are intrameniscal signal anomalies. This may explain the moderate intra- and interobserver reproducibility regarding the treated meniscus, where suture leads to segmentation imprecisions. MITK 3M3 software is simple and free to use in all settings. It is less reproducible regarding estimation of meniscal volume than other parameters. Other teams used deep learning methods or machine learning methods to segment the meniscus in adult patients with interesting results.[23-25]

Presurgical meniscus coverage for the 2 cases of meniscus luxation was probably underestimated. Indeed, when the meniscus moves behind, its projected surface is sometimes out of the corresponding tibial surface (Supplementary Fig 2). This shows the importance of articular position during MRI. To be extremely reliable, the MRI would need to be performed in a position where the meniscus is not in luxation (hyperflexion for posterior disinsertion and hyperextension for anterior disinsertion).

Limitations

Our study is small and retrospective. Meniscus segmentation had a weak to moderate reproducibility (ranging from 0.4 to 0.78), and the absolute accuracy of the MITK 3M3 software has not been validated up to date. Longer clinical and radiologic follow up is required to evaluate the long-term results of meniscus

Table 3. Surface and Volume Intra- and Interobserver Correlation (κ Coefficient)

Correlation		Intraobserver	Interobserver
Cartilage surface		0.78	0.87
Meniscus surface	Before surgery	0.78	0.57
	After surgery	0.42	0.44
Meniscus volume	Before surgery	0.72	0.41
	After surgery	0.65	0.4

saucerization and to evaluate the long-term remodeling of meniscus. Similarly, this study did not use patient-reported outcome measurements.

Conclusions

The meniscoplasty suture-saucerization procedure may allow meniscus sparing and restauration of a similar to normal meniscus volume. Meniscus surface and coverage are diminished compared to controls. Both surface and volume normalization is usually not achievable without decreasing the thickness of the rather thick discoid meniscus.

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