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Width is a more important predictor in graft extrusion than length using plain radiographic sizing in lateral meniscal transplantation

Bum-Sik Lee · Jong-Won Chung · Jong-Min Kim · Kyung-Ah Kim · Seong-Il Bin

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Abstract
Purpose Plain radiographs are frequently used to select appropriately sized meniscal allografts, of which the width and length cannot be always perfectly matched. The objective of this study was to decide which of these dimensions should be matched with a more priority considering proper position of the lateral meniscal transplants.
Methods The positions of 34 lateral, fresh-frozen meniscal allografts, transplanted using the central bone bridge method, were evaluated by magnetic resonance imaging (MRI) 2 days after surgery. A size mismatch was defined as a difference between preoperative radiographic size and a real dimension of the transplants. The lateral subluxation of the mid-body on the coronal plane and the anterior and posterior horn positions on the sagittal plane were estimated on the MRIs. It was evaluated whether size mismatches were associated with the meniscal subluxation beyond articular cartilage margin on each plane.
Results The mean lateral subluxation of the mid-body on the center of coronal sections was 1.7 ± 1.8 mm. The anterior and posterior horns were located 2.0 ± 2.1 mm and -3.8 ± 2.7 mm from the articular edge, respectively, in the center of sagittal images. Lateral subluxation was significantly associated with width mismatch ($r = 0.415$–0.486, $P < 0.05$), but length mismatch was not significantly correlated with the anterior or posterior horn position on sagittal images (n.s.).
Conclusion The results of this study suggest that width matching using plain radiographs would be more reliable than length matching when it is sought to assure adequate positioning of meniscal transplants, if both dimensions cannot be simultaneously matched.
Level of evidence II.

Keywords Meniscus · Meniscal allograft transplantation · Size · MRI

B.-S. Lee
Department of Orthopaedic Surgery,
Incheon St. Mary's Hospital, College of Medicine,
Catholic University, Bupyeong 6-dong, Bupyeong-gu,
Incheon 403-720, South Korea

J.-W. Chung
Department of Orthopaedic Surgery,
CHA Bundang Medical Center, College of Medicine,
CHA University, 351 Yatap-dong, Bundang-gu,
Seongnam-si, Gyeonggi-do 463-712, Korea

J.-M. Kim · S.-I. Bin (✉)
Department of Orthopaedic Surgery, Asan Medical Center,
College of Medicine, Ulsan University, 388-1, Pungnap-2-dong,
Songpa-gu, Seoul 138-736, South Korea
e-mail: sibin@amc.seoul.kr

K.-A. Kim
Department of Biomedical Engineering, College of Medicine,
Chungbuk National University, Gaesin-dong, Heungdeok-gu,
Cheongju, Chungcheongbuk-do 361-763, South Korea

Introduction

The goals of human meniscal transplantation are to afford functional improvement following restoration of the contact area, to reduce contact stress, and to relieve pain in symptomatic meniscectomized knees [9, 13, 21]. The single bone bridge method, commonly used for lateral meniscal transplantation, provides secure fixation strength to the tibia [2, 29], but accurate size matching is essential because horn positions cannot be adjusted. A biomechanical study suggested that a mismatch <10% of the size of the original meniscus is acceptable in lateral meniscal transplantations [3].

In clinical practice, any direct measurements of the original meniscal dimensions are not allowed because the patients who need meniscus transplantation already lost their own menisci. Therefore, indirect radiographic measurements of proximal tibial bony landmarks are generally used to determine a mediolateral width and an anteroposterior (AP) length of meniscal transplants [8, 18, 19, 23, 31]. Unfortunately, it is very difficult to simultaneously match the exact sizes of both dimensions. If a perfect sized graft is not available, just one of the two measurements should be matched a more priority, rendering mismatch in the other one inevitable.

We assessed the size mismatches between preoperative measurements and the dimensions of real meniscal allografts, and the influences of a mismatch in width or length on, respectively, lateral or anterioposterior extrusion from the articular margin based on the MRI performed on postoperative day 2. The objective of this study was to decide whether width or length should be matched with a more priority considering accurate graft position by the most popular sizing method described by Pollard et al. [18]. We hypothesized that sizing the mediolateral width of the preoperative radiographs is a more important predictor of whether the meniscus extrudes beyond articular margin of the lateral tibial plateau than the AP length, as determined by measurements taken on a postoperative MRI.

Materials and methods

This study was approved by our institutional review board. Thirty-four consecutive patients (22 men, 12 women) with a median age of 32 years (range, 19–48 years) underwent lateral meniscal allograft transplantation, each on a single knee, between March 2009 and June 2010. All meniscal allografts were transplanted using the keyhole technique by a single senior orthopedic surgeon (SIB) of our institution. All 34 patients had previously undergone subtotal or total meniscectomy of the lateral meniscus and complained of lateral compartment pain of the affected knee despite conservative treatment for at least 6 months. At least 2 mm of joint space was preserved on a 45° flexion weight-bearing posteroanterior radiograph. Long-standing radiographs showed no malalignment of the lower limbs requiring surgical correction. Five patients had previous histories of anterior cruciate ligament reconstruction, and ligament stability was confirmed by physical examination preoperatively.

Preoperative radiographic sizing and measurement of real allograft dimensions

Under magnification control (10% enlargement), a true AP radiographs was taken at full extension and a true lateral image was taken after 20–30° of flexion to ensure acceptable radiography showing superimposition of the femoral condyles within 3 mm. A radio-opaque rod 100 mm in length was attached to the lateral epicondyle of the femur after palpation and perpendicularly to the center of the front of the patella for AP and lateral images, respectively. After the Roentgen tube was turned on, the tube distance was adjusted until the shadow of the rod parallel to the image recording plate was 110 mm, measured using a ruler, and the sizing radiographs were taken.

Meniscal dimensions of the affected knee were estimated using the length measurement tool of the Picture Archiving Communication System (PACS, Asan Medical Center, Seoul, Korea) according to the methods described by Pollard et al. [18]. On AP radiographs, the lateral meniscal width equaled the distance from the peak of the tibial eminence to the metaphyseal margin of lateral compartment. The length of each lateral meniscus was estimated at 70% of the measured plateau length on lateral radiographs. After confirming that the length of the rod was 110 mm on each images, the actual size was derived from the measured size after magnification correction. The length measurement tool of the PACS allows two decimal places, but the value was rounded to one decimal place which was sufficient to examine our hypothesis. Preoperative radiographic measurements of each patient were taken independently by two orthopedic surgeons, and the average of the two measurements was used to guide transplantation.

The estimated sizes of the desired meniscus were informed to the tissue bank (Korea Bone Bank, Seoul, Korea), and thereafter, fresh-frozen allograft was supplied that was best-fitted and never exceeded 10% mismatch in width and length [3, 8, 31]. Intraoperatively, the mediolateral width and AP length of each real allograft was measured, after preparation, with photographs taken to ascertain actual size (Fig. 1).

Transplantation of meniscal allografts using the keyhole technique

The allograft was implanted with the keyhole technique, which meant that the anterior and posterior horns of the meniscus were fixed in position by connecting bone bridge. Therefore, we put the special attention to an accurate placement of the keyhole position, which was determined under C-arm intensifier. A guide pin was positioned in the AP direction just under the lateral tibial eminence, parallel to the posterior slope of the tibial plateau. The accurate placement of guide pin was confirmed on C-arm image, and thereafter, a cannulated reamer 10 mm in diameter was placed over the pin to ream a tunnel. Subsequently, a burr and rongeur were used to remove lateral tibial eminence and prepare the tibial slot.

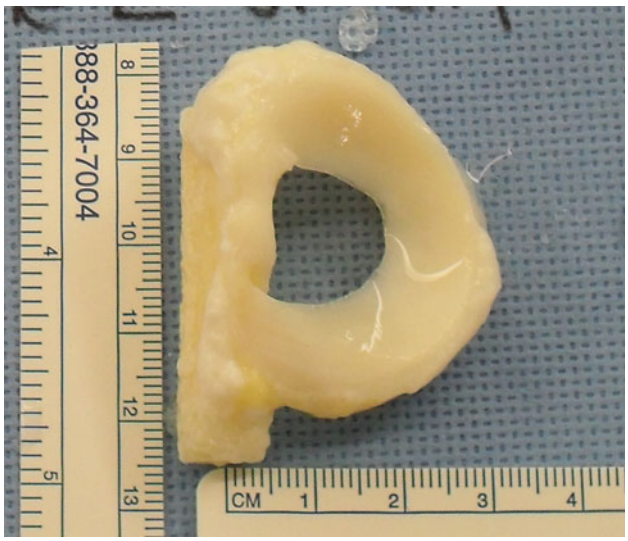


Fig. 1 A sample photograph allowing measurement of real allograft transplants after preparation. The photograph was taken with two paper rulers placed perpendicular to each other

The remaining host meniscus was resected arthroscopically, leaving a peripheral rim about 1 mm in depth to permit punctate bleeding. The meniscal allograft was introduced through anterior mini-arthrotomy. After confirming optimal allograft positioning and seating in the joint, traditional inside-out meniscal repair was done with 10–12 vertical No. 2–0 nonabsorbable sutures, 3–5 mm apart at the mid-portion and posterolateral region of the meniscal allograft. The anterior part of the meniscal allograft was sutured to the anterior capsule under direct visualization.

Postoperative measurements of graft position

MRI scans (Achieva 3T; Philips Healthcare, Best, the Netherlands) of the operated knee were taken 2 days after transplantation, to exclude any secondary changes in transplants caused by remodeling. Conventional MRI is noninvasive and appropriate for our purpose to assess the meniscal positions. Scans were taken in the supine position, with the knee fully extended. Graft positions were evaluated on sagittal and coronal proton density-weighted (PDW) fast spin echo images. Sagittal images were acquired with a 1.5 mm slice thickness, and coronal images were scanned with 2.5 mm slice thickness. The position of the mid-body was assessed in terms of lateral subluxation on seven consecutive coronal images that covered the entire mid-body region. Subluxation was defined as the distance between the outer edge of the articular cartilage of the tibial plateau and the meniscal outer edge (Fig. 2a) [7, 10, 11, 15, 26]. The anterior and posterior horn positions were also evaluated on seven consecutive sagittal images

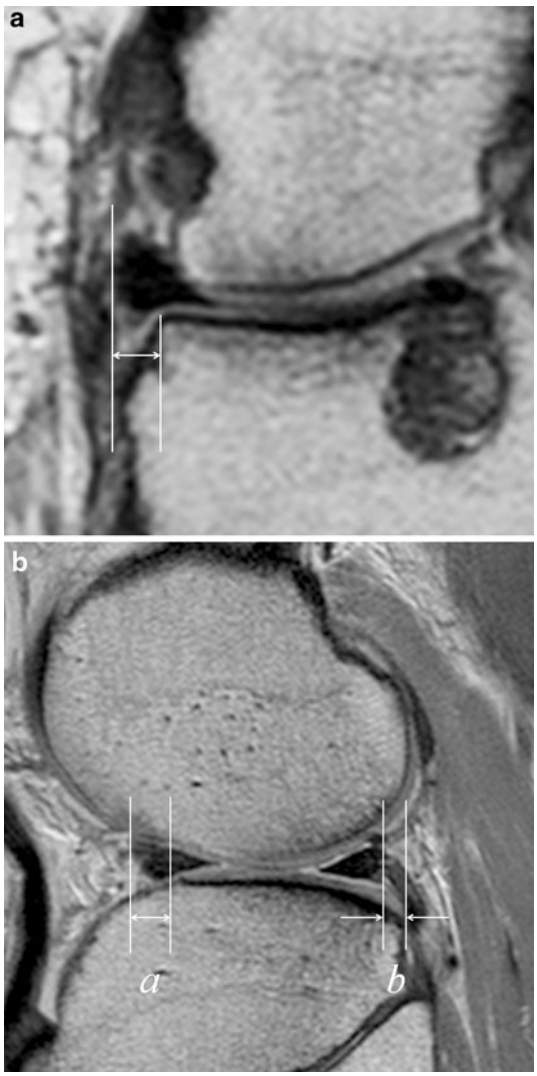


Fig. 2 Measurements of meniscal positions. **a** Lateral subluxation on a coronal image. **b** Anterior (*a*) and posterior (*b*) horn positions, determined as distances from the osteocartilage junction

that covered the entire anterior and posterior horns. Each horn position was calculated as the distance from the osteocartilage margin to the most peripheral margin of the meniscal transplant, anteriorly or posteriorly (Fig. 2b). MRI results were evaluated independently by two orthopedic surgeons with significant knee MRI experience. Each surgeon measured the position of each meniscal transplant to one decimal point, twice, at an interval of 2 weeks. The averages of these measurements were employed in analysis.

Statistical analysis

All statistical analyses were performed using SPSS version 16.0 for Windows (SPSS Inc., Chicago, IL), and $P < 0.05$

Table 1 Intraclass correlation coefficients (ICCs) of inter- and intra-observer errors of measurement

	Interobserver	Intraobserver	
		1	2
Preoperative radiographic measurement*			
Width	0.939	–	–
Length	0.818	–	–
Postoperative meniscal position on MRI			
Lateral subluxation	0.820	0.893	0.926
Anterior horn position	0.906	0.962	0.933
Posterior horn position	0.960	0.965	0.954

* Preoperative radiographic measurements were taken once by each observer

were considered significant. The reliability of measurements of preoperative radiographic sizing and postoperative meniscal position on MRI was assessed by the calculation of the intraclass correlation coefficient (ICC). Inter- and intraobserver reliability was good (Table 1). The differences between preoperative measurements and the dimensions of real meniscal allografts were determined by paired *t*-test. Width mismatch was calculated by subtracting mediolateral measurements on AP radiographs from real allograft widths, and length mismatches were obtained by subtracting lengths on lateral radiographs (70% of measured plateau lengths) from real allograft lengths. A positive value indicates that an allograft was larger than the measured size in the relevant dimension, while a negative value means that an allograft was smaller than the measured size. Relative mismatches were calculated by dividing each mismatch by the preoperative measurement. The Pearson correlation test was used to assess the association between size mismatch and meniscal position on immediate postoperative MRIs (i.e., between width mismatch and lateral subluxation of the mid-body, and between length mismatch and the anterior or posterior horn position).

Results

Graft sizing and mismatching of real allograft dimensions

Radiographic measurements did not differ significantly from the real dimensions of transplanted allografts (paired *t*-test, n.s.). The average width and length mismatches for all 34 patients were -0.2 ± 0.9 mm and 0.1 ± 2.3 mm, respectively, with relative width mismatches of -5.3 to 8.3% (mean, $-0.6 \pm 2.9\%$) and relative length mismatches of -10.0 to 9.4% (mean $0.5 \pm 6.2\%$). However, no mismatch was $\geq$10% of a preoperative measurement (Table 2).

Meniscal position on MRI 2 days after surgery

The mean lateral subluxation of the mid-body on the center of coronal sections was 1.7 ± 1.8 mm (Table 3), with 9 of 34 (26.5%) knees having extrusions >3.0 mm in length. In the more anterior portion of the mid-body, lateral subluxation was exacerbated, as determined by both extent and incidence. In the more posterior coronal images, the mid-body showed less subluxation (Fig. 3a). In the center of sagittal images, the anterior horn was situated an average

Table 3 Lateral subluxation and numbers of extrusions on coronal images

	Subluxation (mm)		Extrusion (>3.0 mm)	
	Mean ± SD	Range	No.	%
1 (most anterior)	2.7 ± 1.9	-0.6–7.5	16	47
2	2.4 ± 1.9	-1.0–6.8	16	47
3	2.1 ± 1.8	-1.1–6.1	12	35
4 (center)	1.7 ± 1.8	-2.4–5.8	9	26
5	1.2 ± 1.7	-2.9–5.5	5	15
6	0.2 ± 1.7	-3.7–4.5	3	9
7 (most posterior)	-1.2 ± 1.7	-4.8–3.2	1	3

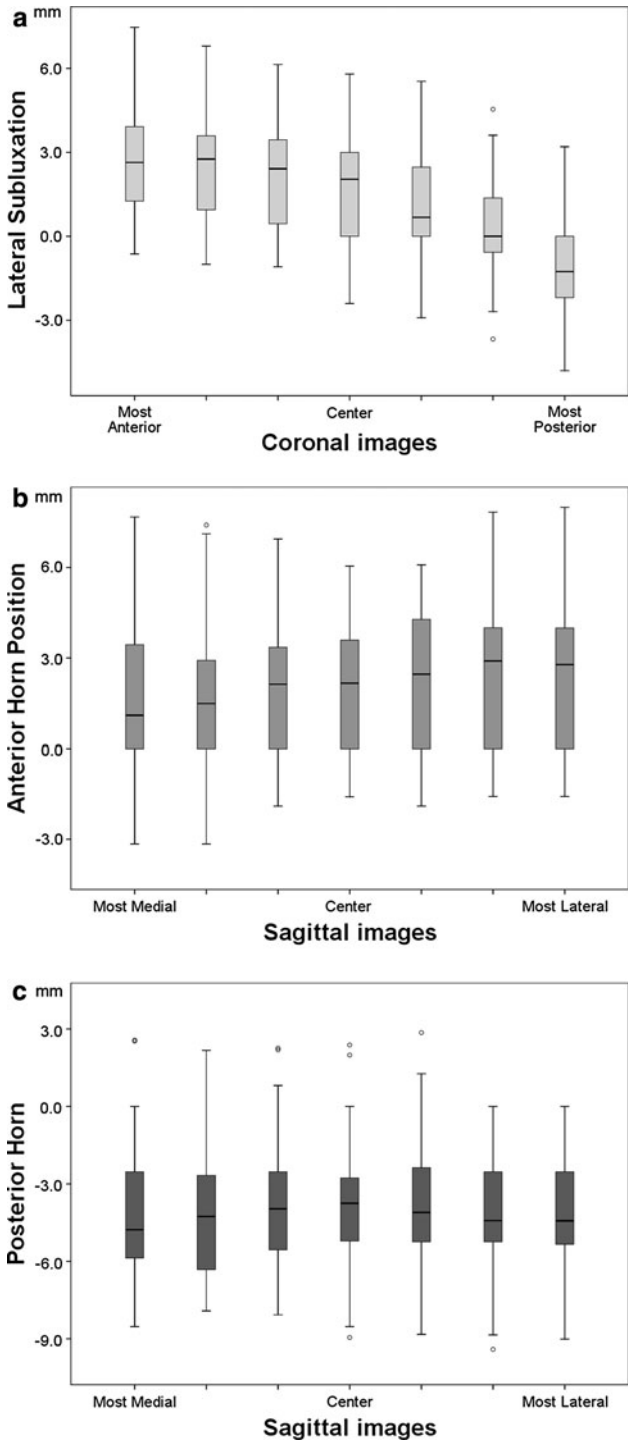
Table 2 Preoperative radiographic measurements using Pollard's method, and real allograft size

	Radiographic measurement	Size of real allograft	Mismatch*		Relative mismatch[a]
				P	
Width	31.2 ± 2.9	30.9 ± 2.8	-0.2 ± 0.9	n.s.	$-0.6 \pm 2.9\%$
	(25.2–36.4)	(25.0–36.0)	(-1.7–2.3)		(-5.3–8.3)
Length	38.2 ± 3.2	38.3 ± 3.1	0.1 ± 2.3	n.s.	$0.5 \pm 6.2\%$
	(32.3–43.9)	(32.0–45.0)	(-4.2–3.7)		(-10.0–9.4)

Means ± SDs; all dimensions are in mm; ranges in parentheses

* Mismatch = real size of allograft—preoperative measurement on plain radiographs

[a] (mismatch/preoperative measurement) × 100 (%)



◀ **Fig. 3** Histogram of meniscal transplant positions on seven consecutive images of each plane, which was measured by MRI 2 days postoperatively. The *Y-axis* represents the distance between the osteocartilage margin of the lateral tibial plateau and the meniscal peripheral edge. A *positive value* indicates that an allograft was extruded beyond articular margin, while a *negative value* means that an allograft was located inside the articular edge. **a** Lateral subluxation of the mid-body was exacerbated in the more anterior coronal images. **b** The anterior horns tended to be anteriorly subluxated over the edge of the cartilage. The degree of anterior subluxation decreased closer to the horn attachment (most *medial*). **c** The posterior horns were located within the posterior articular margin across the sagittal images

of 2.0 ± 2.1 mm anteriorly from the articular margin, and the posterior horn was located a mean of −3.8 ± 2.7 mm inside the posterior articular edge. The degree of anterior subluxation decreased closer to the point of horn attachment (Fig. 3b), whereas the posterior horn position showed no tendency toward deviation across the sagittal cuts examined (Fig. 3c).

Correlation between size mismatch and meniscal position

We observed moderately positive correlations between width mismatch and lateral subluxation ($0.4 < r < 0.5$, $P < 0.05$) (Table 4). The correlation coefficients were similar across all examined coronal images, although the degree of extrusion differed. On the other hand, we observed no significant association between length mismatch and anterior or posterior horn position in any sagittal image (Table 5).

Table 4 Correlation between width mismatch and transplant lateral subluxation

	r	*P* value
1 (most anterior)	0.452	0.007
2	0.415	0.015
3	0.412	0.016
4 (center)	0.446	0.008
5	0.486	0.004
6	0.448	0.008
7 (most posterior)	0.414	0.015

Table 5 Correlation between length mismatch and the positions of anterior and posterior horns

	Length mismatch vs. AH position		Length mismatch vs. PH position	
	r	*P* value	*r*	*P* value
1 (medial)	0.138	n.s.	0.059	n.s.
2	0.076	n.s.	0.094	n.s.
3	0.069	n.s.	0.124	n.s.
4 (center)	0.134	n.s.	0.149	n.s.
5	0.039	n.s.	0.120	n.s.
6	−0.024	n.s.	0.189	n.s.
7 (lateral)	−0.031	n.s.	0.249	n.s.

AH anterior horn, *PH* posterior horn

Discussion

The most important finding of the present study was that mediolateral width matching was more predictive of whether the meniscus extrudes beyond articular margin than AP length matching. In the present study, the position of allografts was determined by MRI 2 day after operation to exclude any secondary changes. The immediate postoperative position of transplants is important because it might be maintained at least over remodeling period. A serial MRI evaluation showed that the lateral extrusion of the meniscal transplants did not changed during first postoperative periods [11].

Inaccurate preoperative sizing can adversely affect meniscal function [3, 22]. Anatomically placed and properly sized meniscal allografts are necessary to restore biomechanical function, to alleviate pain, and to ensure good long-term prognosis, including a possible chondroprotective effect [1, 17]. It has been recommended that the donor meniscus be of a size within 5–7% that of the native meniscus, [8, 13] and menisci ±10% in size with respect to the original meniscus have been found to restore contact biomechanics to a state that is close to normal [3]. When a lateral meniscal allograft is transplanted using a bone bridge, employing a trough or keyhole technique, the horn attachment is reproduced by the anatomic features of the allograft, which cannot be altered. Thus, adequate functional restoration requires accurate preoperative determination of size as well as correct positioning of the bone bridge; this should be as close to that of the original lateral meniscus as possible [8, 30].

Although several studies have evaluated preoperative meniscus sizing methods, most work have been performed under meniscus-intact conditions, in cadaveric knees [4, 14, 18, 19, 23, 25, 31]. In actual clinical practice, the real size of the original meniscus of a meniscectomized knee cannot be determined precisely, so that size is indirectly estimated by methods derived from sizing studies on meniscus-intact knees. Although MRI measurement of the contralateral normal meniscus may be optimally accurate [19], it is difficult to determine meniscal dimensional symmetry of the right and left knees [14, 23]. Therefore, preoperative measurements using magnification-controlled plain radiographs are generally regarded as simple and acceptable in terms of sizing for meniscal transplantation [8, 13, 16, 21, 31].

Unfortunately, individual anatomic variation in the proximal tibia [6, 7, 12] makes it difficult to select exact-sized transplants, matched to both mediolateral and AP measurements, even if tissue banks have a large inventory of donor menisci. Consequently, a choice must be made as to whether matching of width or length affords better outcomes. Some leeway exists, however, because indirect radiographic measurements cannot absolutely determine the size of the original meniscus. It has remained unclear which of these dimensions should assume priority when matching is considered. We found that more appropriate positioning of meniscal transplants occurred when allografts were matched by width rather than by length.

Unexpectedly, we did not observe any association between length mismatch and meniscal position on the sagittal plane, although we found that length mismatch had a larger standard deviation and a wider range than did width mismatch. We presume these might be inherent to anatomic variations in the lateral tibial plateau [6, 12]. For example, low correlation between the AP length of lateral tibial articular surface and that of tibial plateau might lead to errors in length measurements of menisci on lateral radiographs. Radiographic measurements of length have been reported to be of low accuracy in Asian populations [31]. Pollard et al. [18] also mentioned that AP films were easier to standardize and the anterior and posterior horns were not collinear in a pure sagittal plane. Although our findings suggest that priority of consideration should be given to matching of mediolateral width, it should be noted that AP length measurements were not completely ignored and matched within acceptable range of 10% [3] in the present study.

Another finding is that the anterior horn appeared to be subluxated anteriorly over the osteocartilage junction on sagittal images and that lateral subluxation of the mid-body was aggravated, from posterior to anterior, on coronal images. These results are similar to those afforded by comparisons of lateral meniscal allografts and normal menisci, which showed that the anterior horn of a transplanted lateral meniscus tended to be more extruded than the posterior horn [27]. However, the cited study did not employ bone fixation, and the degree of extrusion was greater than what we observed. These findings suggest that a tendency toward anterior subluxation should be considered when performing meniscal transplantation.

This study had several limitations, including a small number of patients. In addition, surgical errors could not be completely excluded and may have contributed to inappropriate positioning of transplants. A meniscal transplantation with bone bridge method is technically demanding, and the meniscal horn insertions are determined by a position of bone bridge [30]. Thus, a correct position of the bone tunnel is also important in postoperative graft positioning as well as accurate sizing. To minimize associated errors, we confirmed tunnel position and angle intraoperatively, using a C-arm intensifier, and determined the most stable allograft position with appropriate tie tension via arthroscopic visualization. A cadaveric study suggested that intraoperative radiologic determination of the tibial insertion of anterior and posterior horns might be a highly reliable method in lateral

meniscus transplantations [28]. Nevertheless, technical error may explain, at least in part, the relatively low correlation noted between size mismatch and graft position. We also considered that the osteocartilage junction was a suitable reference point by which to position the anterior or posterior horn. This may be inadequate if meniscal position is to be analyzed on sagittal images, although MRI scans were always taken under full extension. The mid-body of the lateral meniscus has little medial–lateral motion relative to the degree of knee flexion, but the anterior and posterior horns are mobile during knee motion [20, 24, 26], making it difficult to establish a normal reference point for the anterior and posterior positions. Several previous studies have used the osteocartilage junction as a meniscal positional reference on MRI [7, 15, 20, 26], suggesting that this is acceptable in terms of addressing the effect of size mismatch on meniscal position. In addition, measurements were taken on several sagittal images, and the results from adjacent cuts were relatively similar. Another limitation was our exclusive use of the keyhole technique for transplantation. Different results may be obtained if soft tissue or bone plug methods are employed [5, 27].

Despite these limitations, the present study is the first to address the size mismatches that are inevitable during graft selection. Our results may guide radiographic size selection when a precisely size-matched allograft is not available in clinical practice.

Conclusion

The mediolateral width would be a more important predictor of whether the meniscus extrudes beyond articular margin of the lateral tibial plateau than the AP length, when the dimension of meniscal allograft is determined using the preoperative radiographic method described by Pollard et al. [18].

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