Meniscal Root Tears: A Classification System Based on Tear Morphology

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Meniscal Root Tears

A Classification System Based on Tear Morphology

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Background: Meniscal root tears present in many forms and can have profound consequences on the health of knee articular cartilage. While the biomechanics, natural history, and treatment of root tears have been increasingly investigated, the spectrum of meniscal root tear patterns observed during arthroscopic examination has yet to be defined and categorized.

Purpose: To establish a classification system for meniscal root tears by reporting the morphology of meniscal root tears from a consecutive series of arthroscopic surgeries. It was hypothesized that meniscal root tears could be grouped into types by distinct tear patterns and that recognition of tear pattern would affect treatment choice.

Study Design: Case series; Level of evidence, 4.

Methods: All patients who underwent arthroscopic surgery from April 2010 to May 2014 by a single orthopaedic surgeon were included. After arthroscopic examination, data regarding the integrity of the meniscal roots were prospectively recorded in a data registry. Tear morphology and treatment received were subsequently extracted by 2 independent reviewers from operative notes and arthroscopic surgical photos.

Results: A total of 71 meniscal root tears in 67 patients were grouped into tear types with similar tear morphologies. Meniscal root tear patterns were categorized into partial stable root tears (type 1; n = 5); complete radial tears within 9 mm of the bony root attachment (type 2; n = 48), further subclassified into types 2A, 2B, and 2C, located 0 to <3 mm, 3 to <6 mm, and 6 to 9 mm from the root attachment, respectively; bucket-handle tears with a complete root detachment (type 3; n = 4); complex oblique tears with complete root detachments extending into the root attachment (type 4; n = 7); and bony avulsion fractures of the root attachments (type 5; n = 7).

Conclusion: This study demonstrated that it was possible to establish a concise classification system to group patients with meniscal root tears by tear morphology. Treatments received varied across tear types.

Keywords: meniscus root; meniscus root tear; radial tear; classification

The meniscal root attachments have garnered increased interest recently because pathologic lesions at or near the root attachment have been reported to significantly alter tibiofemoral contact mechanics, leading to accelerated progression of osteoarthritis.[1,21,23,28,31] In the past, the preferred treatment for meniscal root injury was partial meniscectomy. More recently, clinical studies have linked partial meniscectomy of meniscal tears, specifically tears that are located at the root, with meniscal extrusion and the rapid progression of osteoarthritis in the affected compartment in many patients.[2,29,32,33] Therefore, it is becoming increasingly recognized that meniscal root tears often require repair that attempts to restore the native structure and function of the meniscal root attachments.[3,15,19] Early outcome studies have provided evidence supporting the efficacy of treatment approaches, specifically transtibial pull-out or suture repair, that restore the native structure and function of the meniscal roots after injury.[16,18,22]

Meniscal body and horn tears occur in numerous tear types, including radial, longitudinal, bucket-handle, and degenerative tears,[13,25] with each tear pattern requiring specialized treatment approaches. We believe a distinct distribution of tear morphologies also exists in pathologic lesions observed at the meniscal root attachments. The purpose of this study was to develop a comprehensive classification system for medial and lateral meniscal root tears by reporting the morphology of meniscal root tears from a consecutive series of arthroscopic surgeries. It was

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TABLE 1
Classification of Anterior and Posterior Tears of the Medial and Lateral Meniscal Roots Based on Tear Morphology

Type	Subtype	Description
1		Partial stable meniscal tear 0 to 9 mm from root attachment
2		Complete radial meniscal tear
	2A	Complete radial tear 0 to <3 mm from attachment
	2B	Complete radial tear 3 to <6 mm from attachment
	2C	Complete radial tear 6 to ≤9 mm from attachment
3		Bucket-handle tear with meniscal root detachment
4		Complex oblique meniscal tear extending into the root attachment
5		Avulsion fracture of the meniscal root attachment

hypothesized that it would be possible to classify root tears into distinct types and subtypes.

MATERIALS AND METHODS

This study was approved by the institutional review board. From April 2010 to May 2014, all patients who underwent arthroscopic surgery by a single orthopaedic surgeon (R.F.L.) were evaluated for the presence of meniscal root injury, including root tears or avulsions. Data regarding the integrity of the anterior and posterior roots of the medial and lateral menisci were prospectively documented at the time of surgery and stored in a data registry. At the time of this study, the data registry was queried for all patients with arthroscopically confirmed meniscal root lesions. Inclusion criteria consisted of all patients with arthroscopically confirmed meniscal root lesions. Exclusion criteria were meniscal root tears in meniscal transplants, revision meniscal root repairs, and iatrogenic root tears, which included tears due to anterior or posterior cruciate ligament reconstruction tunnel reaming or tibial intramedullary nail placement.

Using a classification system developed by the senior surgeon (R.F.L.) based on his surgical experience, 2 reviewers independently extracted the data by performing a retrospective review of operative reports and archived arthroscopic images to document the tear morphology, location, proposed classification, and treatment received. Descriptive data regarding tear morphology and classification were compared by the 2 reviewers and evaluated for agreement of characterization. In cases of disagreement or variation from the originally proposed classification system, tear type was settled by consensus among the 2 reviewers and the senior author. Once the data were extracted and finalized, a final classification system using tear morphology was developed to categorize patients into similar groups (Table 1).

TABLE 2
Patient Demographic Information for Each Group Included in the Meniscal Tear Classification

	Age, y		Sex	
	Average	Range	Male	Female
Type 1	35.8	19-65	1	4
Type 2	38.0	14-70	30	18
Type 3	28.3	18-49	4	0
Type 4	30.1	17-68	6	1
Type 5	33.0	21-55	3	4
Exclusions	32.2	21-55	7	3
Total	32.9	14-70	48[a]	29[a]

[a]Patients with multiple tears were only included in the total once.

RESULTS

From April 2010 to May 2014, a total of 1556 knee arthroscopies were performed by a single orthopaedic surgeon. A total of 81 meniscal root tears were identified in 77 patients (48 male, 29 female) with a mean age of 32.9 years (range, 14-70 years) (Table 2). Of the 81 root tears, 10 root tears were excluded. One patient had previously received a meniscal allograft transplantation in which a posterior medial meniscal root tear was discovered. Six patients had a meniscal root tear believed to have originated from iatrogenic injury during anterior or posterior cruciate ligament reconstructions, including 2 anterior medial, 2 posterior lateral, and 2 posterior medial root tears, as documented in previous studies.[17,20] One patient had an anterior medial meniscal root tear due to an iatrogenic tear from a tibial intramedullary nail that was also previously documented.[8] Two patients who underwent revision root repairs were excluded. After these exclusions, a total of 71 meniscal root tears in 67 patients remained to be classified by tear morphology, representing 4.3% of all arthroscopies during the study time period.

Classification of Meniscal Root Lesions

Meniscal root lesions were organized into 5 distinct types (Figures 1 and 2). Type 1 tears were defined as partial stable root tears (with no other concurrent adjacent meniscal body tears) within 9 mm of the center of the root attachment. Type 1 tears accounted for 5 of 71 root tears included in this study (7.0% of all root tears). Type 2 meniscal root tears were defined as complete radial tears within 9 mm of the center of the root attachment. These were the most common type of tears and seen in 48 of 71 patients (67.6% of all root tears). Type 2 tears were further classified into type 2A, defined as complete radial meniscal tears 0 to <3 mm from the center of the root attachment; type 2B, defined as complete radial meniscal tears 3 mm to <6 mm from the center of the root attachment; and type 2C, defined as complete radial meniscal tears 6 to 9 mm from the root attachment. There were 27 type 2A

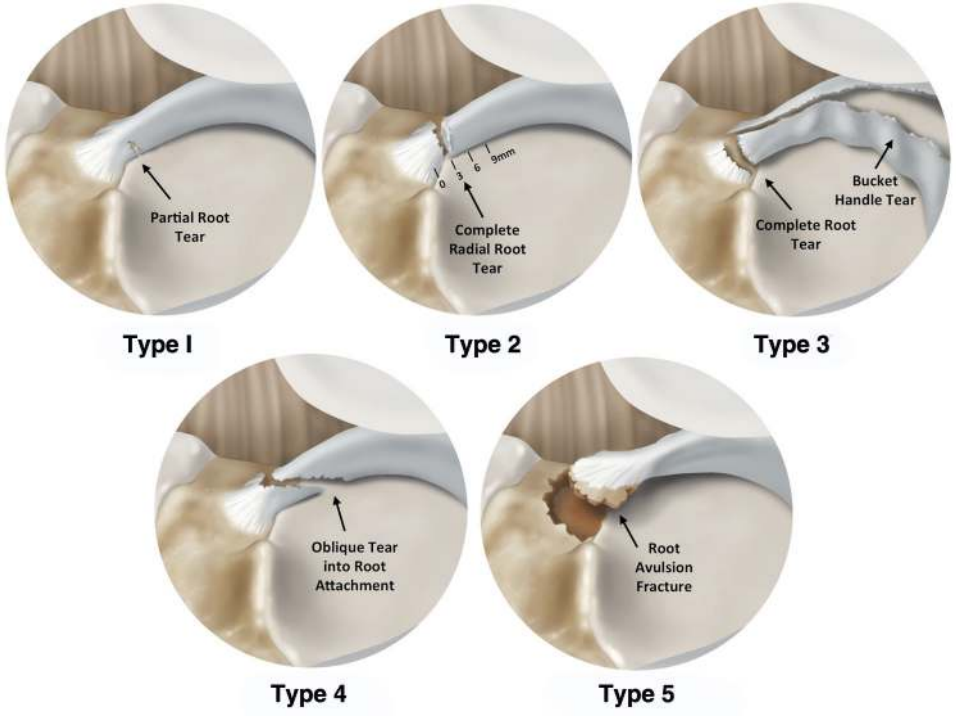

Figure 1. Illustrations of the meniscal root tear classification system in 5 different groups based on tear morphology. All meniscal tears are shown as medial meniscal posterior root tears for consistency in this illustration. The 5 tear patterns were classified based on morphology: partial stable root tear (type 1), complete radial tear within 9 mm from the bony root attachment (type 2), bucket-handle tear with complete root detachment (type 3), complex oblique or longitudinal tear with complete root detachment (type 4), and bony avulsion fracture of the root attachment (type 5).

tears (38.0% of all root tears), 12 type 2B tears (16.9% of all root tears), and 9 type 2C tears (12.7% of all root tears). Type 3 meniscal root tears were defined as bucket-handle tears with complete detachment of the meniscal root attachment within 9 mm of the center of the root attachment. Type 3 root tears accounted for 4 of 71 root tears (5.6% of all root tears). Type 4 root tears were defined as complex oblique meniscal tears leading to complete root detachment within 9 mm of the center of the root attachment. Type 4 tears were found in 7 of 71 root tears (9.9% of all root tears). Type 5 tears were defined as avulsion fractures of the meniscal root off the tibial plateau. Type 5 tears were found in 7 of 71 root tears (9.9% of all root tears). Of the patients with type 5 tears, 5 had comminuted tibial eminence fractures, 1 had a posterior cruciate ligament (PCL) tibial avulsion fracture, and 1 patient had a tibial plateau fracture.

Finally, we identified a variant of a posterior lateral meniscal root tear in which the meniscofemoral ligament(s) were intact. This was defined as a "meniscofemoral ligament variant" root tear (Figure 3). We observed that, when present, the meniscofemoral ligament(s) conferred stability to the posterior lateral root tears, preventing the increased mobility and meniscal extrusion that is often observed in other types of meniscal root tears. Because these tears appeared to behave differently, they were considered a variant tear type. These variant tears were first recognized and documented during the final 18 months of the study. The overall prevalence of these tears was not reported in this current study because the reporting of these variant tears was not consistent throughout the entire study period. Among the meniscofemoral ligament variant tears observed during the final 18 months of the study, all 4 with intact meniscofemoral ligaments (out of 21 overall posterior lateral root tears during this time period) were type 2 tears.

Location and Chronology of Root Tear Lesions

Of the 71 meniscal root tears included in this study, a total of 5 root injuries were documented in the anterior roots (Table 3). All were anterior lateral root injuries, and all were bony avulsion fractures (type 5 tears). There were 66 injuries to the posterior meniscal roots, including 29 to the posterior lateral root (40.8% of all root tears) and 37 to the posterior medial root (52.1% of all root tears) (Table 3).

The chronology of meniscal root lesions before surgical treatment varied among tear types. For root tears of types 1, 2, and 4, approximately equal numbers of patients presented with acute and chronic tears. By contrast, tears of types 3 and 5 were all acute tears (Table 3). Type 5 tears, or avulsion fractures, were not subject to this distinction since they would occur directly at the root attachment. While these bony avulsions usually present acutely, they may also present chronically in what has been called a meniscal ossicle.[3]

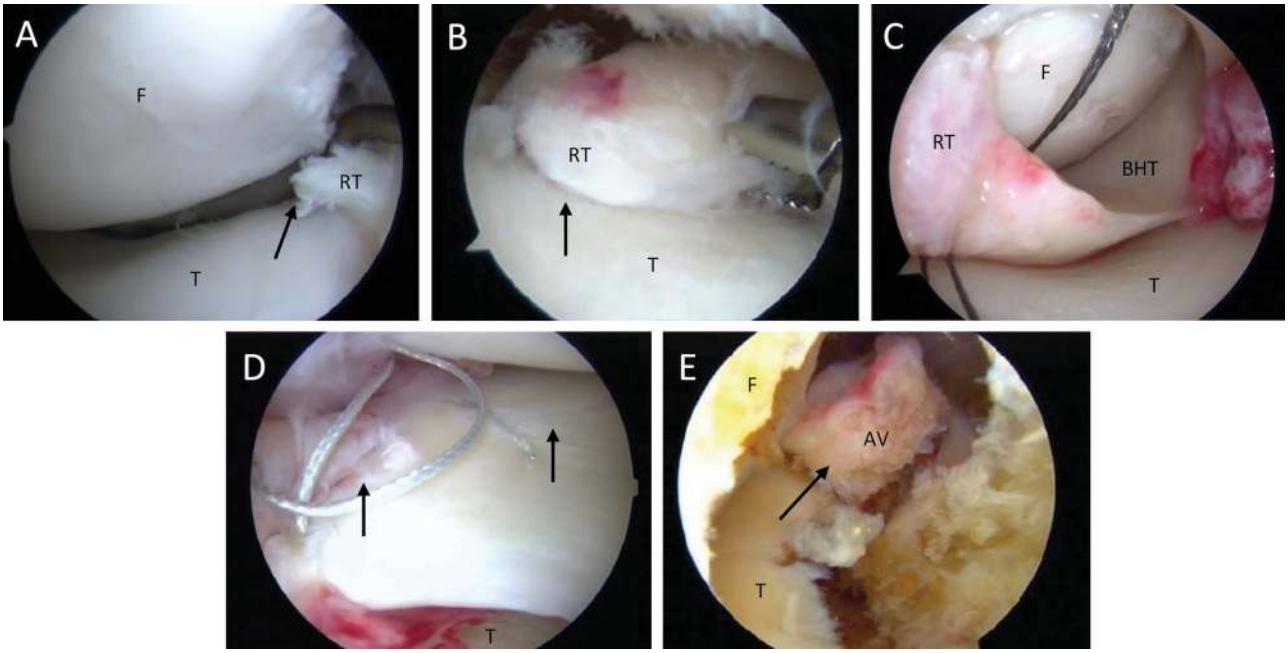

Figure 2. Arthroscopic images of each of the 5 types of meniscal root tears as identified in this classification system. Tear patterns were classified based on morphology: (A) partial stable root tear (type 1), (B) complete radial tear within 9 mm of the bony root attachment (type 2), (C) bucket-handle tear with complete root detachment (type 3), (D) complex oblique or longitudinal tear with complete root detachment (type 4), and (E) bony avulsion fracture of the root attachment (type 5). Arrows correspond to the location of the meniscal tear. AV, avulsion; BHT, bucket-handle tear; F, femur; RT, root tear; T, tibia.

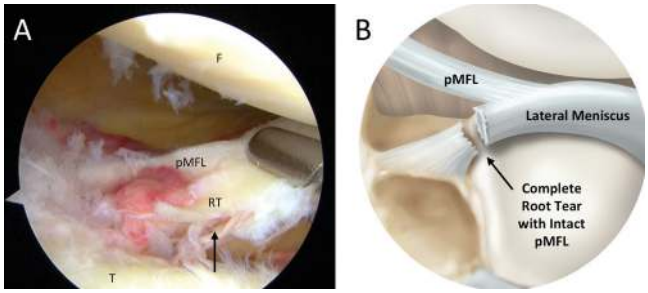

Figure 3. An (A) arthroscopic image and (B) illustration of a complete tear of the posterior lateral meniscal root tear (arrow) stabilized by an intact posterior meniscofemoral ligament (pMFL). F, femur; RT, root tear; T, tibia.

Treatments Received

Treatments received varied within and among root tear classification types (Table 3). The preferred surgical treatment in each patient varied based on the indications for surgical repair or debridement, including age, degree of osteoarthritis, and other concomitant surgical treatments. Repair was more commonly performed than debridement in patients included in this study. The transtibial pull-out repair was the most commonly performed treatment among all root tears in this study, with 55 tears (77.5%) receiving this treatment. Suture repairs, typically inside-out horizontal mattress meniscal repairs, were performed in 6 root tears (8.5%). Debridement (11.3%) was largely reserved for patients with partial stable type 1 tears or those with grade 3 or 4 osteoarthritis in which a meniscal root repair is contraindicated.[3,12] One suture anchor repair and 1 open reduction internal fixation were performed in patients with type 5 injuries.

DISCUSSION

This study demonstrated that it was possible to classify meniscal root tears according to tear morphology. We were able to classify meniscal root tears into 5 tear types: partial stable root tears (type 1), complete radial tears within 9 mm from the bony root attachment (type 2), bucket-handle tears with complete root detachment (type 3), complex oblique or longitudinal meniscal tears with a complete root detachment (type 4), and avulsion fractures of the meniscal root attachment (type 5). In addition, we recorded a specific subtype of posterior lateral meniscal root tears in which a complete meniscal root tear was attached to an intact meniscofemoral ligament(s). We recommend this meniscal root tear classification system be used to establish standardized definitions for various types of meniscal root tears to improve communication regarding meniscal root tears between practitioners and across centers. In addition, this classification system may be used to correlate certain root tear types with a recommended treatment and may facilitate improved reporting of patient outcomes after treatment of meniscal root tears by reporting outcomes separately for each tear type.

TABLE 3
Location, Chronicity, and Treatment of Meniscal Root Tears and Subtypes (N = 71 Knees)[a]

	Location				Chronology		Treatment					
	AM	AL	PM	PL	Acute	Chronic	Debrided	Transtibial	Suture Anchor	Suture Repair	ORIF	Total
Type 1	0	0	1	4	2	3	5	0	0	0	0	5
Type 2	0	0	29	19	24	24	1	45	0	2	0	48
Type 3	0	0	2	2	4	0	0	3	0	1	0	4
Type 4	0	0	4	3	4	3	2	2	0	3	0	7
Type 5	0	5	1	1	7	0	0	5	1	0	1	7
Total	0	5	37	29	41	30	8	55	1	6	1	71

[a]AL, anterior lateral meniscal root; AM, anterior medial meniscal root; ORIF, open reduction and internal fixation; PL, posterior lateral meniscal root; PM, posterior medial meniscal root.

The distance at which a radial tear can be considered a true "root tear" versus a meniscal posterior horn radial tear varies between studies. For example, 2 clinical studies have defined a meniscal root tear as any tear within "the last few millimeters of meniscal tissue angling down to the tibial plateau attachment in the intercondylar notch,"[5,7] while others have defined meniscal root tears as tears within 9 to 10 mm of the root attachment.[6,24] In addition, biomechanical studies have described that complete radial tears up to 9 mm from the root attachment significantly alter the native biomechanics of the posterior meniscal roots.[21,28] In light of the biomechanical data, we established 9 mm as the threshold between what we considered a root tear versus an anterior or posterior horn tear for type 1 to 4 tears. In addition, the subclassification of radial root tears that we present (0 to <3 mm, 3 to <6 mm, and 6-9 mm) has been shown to produce different biomechanical properties with increasing joint loads and decreased contact areas at further distances from the root attachment.[21,28] In turn, these biomechanical changes may also lead to differences in clinical outcomes. For this reason, we believe these are important cutoff values to include in this classification system.

Studies have reported that the prevalence of posterior medial root tears ranges from 10.1% to 21.4% in patients undergoing medial meniscal repair or meniscectomy[4,14,27] and 3.6% of total meniscal tears,[24] while posterior lateral root tears have been reported to be present in 8% to 9.8% in patients undergoing an anterior cruciate ligament (ACL) reconstruction.[5,7] In our study, we found that the prevalence of root tears was 4.3% across all arthroscopic surgeries and that posterior medial and posterior lateral meniscal tears accounted for 52% and 41% of all meniscal root tears, respectively.

Starting in the past 18 months of this study, it became obvious that there was a subtype of posterior lateral meniscal root tears in which the meniscofemoral ligament(s) were intact. Qualitatively, it appeared that the lateral meniscus was tethered by the intact meniscofemoral attachments and did not appear to translate as far laterally as those without the meniscofemoral ligaments intact. Similarly, it has been recently demonstrated in a biomechanical porcine model that complete posterior lateral root tears whose meniscofemoral ligaments remain intact were able to resist deleterious tibiofemoral contact mechanics.[11] A recent clinical magnetic resonance imaging study by Pula et al[30] demonstrated that posterior lateral meniscal root tears often have intact meniscofemoral ligaments that prevent meniscal extrusion. Further studies should investigate the prevalence of these tears.

The prevalence of tears of the anterior meniscal root attachments has not been previously reported, with only case reports documenting these injuries in the literature.[8,10,20,26,34] For the anterior medial meniscal root, case reports have reported iatrogenic injuries during intramedullary tibial nailing, ACL reconstruction, and cyst resection,[8,10,20] as well as injury attributed to variant attachments of the anterior medial root.[26] In our current study, we did not record any injuries to the anterior medial root in a series of 71 root tears. We are aware of only 1 case report of an anterior lateral root tear.[34] In our study, we found that all anterior lateral root tears (7.1% of all root tears) were either associated with comminuted tibial eminence fracture, PCL tibial avulsion fractures, or tibial plateau fracture.

While it was not a goal of this study to define clinical outcomes or to specify the optimal treatment for each type of meniscal root tear, we believe it is important to review the types of repairs performed for the types of meniscal root tears to demonstrate the importance of this classification system. In this study, the transtibial pull-out repair technique was the most commonly used treatment method (77.5% of knees), which was performed in a manner consistent with the majority of the reported techniques in the literature for meniscal root repairs.[1,3,21-23,28,31] This technique uses a transtibial bone tunnel to shuttle and secure sutures from the meniscal root tissue over a surgical button on the anterior aspect of the tibia. Other studies have described the use of a suture anchor technique, which may help reduce displacement of the repair construct[9]; however, this technique has been reported to be difficult to ensure anatomic placement of a suture anchor in the small tibiofemoral space, especially in the absence of a concurrent grade 3 medial collateral ligament tear.[3] In this series, suture anchor repair was used in only 1 patient (1.4%) for an anterior type 5 tear.

Suture repair consisting of an inside-out horizontal mattress repair may be another viable option for meniscal root

tears in which substantial healthy meniscal tissue is present on both sides of the tear. As seen in this study, suture repair was used in 8.5% of all root repairs across tear types 2, 3, and 4. For type 4 tears, we found that 3 of 7 tears were treated with horizontal mattress sutures because of the obliquity of the tear. For type 3 tears, which include a bucket-handle tear of the meniscal body, the preferred method of fixation was to first anchor the meniscal root attachment using a transtibial pull-out technique followed by an inside-out suture repair of the meniscal body. Other treatments, such as debridement, do not repair the meniscal lesion and are instead indicated for patients with partial stable tears, as seen in a type 1 tears, or in patients with advanced articular cartilage degeneration of the knee, a common contraindication for meniscal root repair.[3,12] Debridement of a meniscal root tear was used in only 8 patients (11.3%).

We believe that this root tear classification system is important because it is the first standardized classification system that encompasses tears that may be seen in all the meniscal roots. The different tear patterns may require different methods of treatment, which will need to be further defined through clinical outcome studies. In addition, this classification system also sets out to create a more defined distinction between true meniscal root tears and tears of the meniscal horns or midbody by establishing a threshold of 9 mm from the center of the root attachment for type 1 to 4 tears. Type 5 tears, or avulsion fractures, were not subject to this distinction, as they would occur directly at the root attachment. Studies should aim to evaluate the postsurgical outcomes after meniscal root tears at different locations and across different morphologies to determine the best methods of treatments for each specific tear pattern.

We acknowledge some limitations to this study. First, this was a retrospective analysis of prospectively collected data. While retrospective, all tear morphology was carefully documented, and when the tear type was in doubt, the original arthroscopic photographs were reviewed. Also, these patients were evaluated and treated at a complex knee referral practice and results may not be extrapolated to all orthopaedic settings. Last, given the complexity of the meniscal tear patterns, we believe that this classification system of 5 different tear morphologies encompasses the wide range of meniscal tears in a succinct format. However, further studies should investigate the prevalence of posterior lateral root tears with and without intact meniscofemoral ligaments.

CONCLUSION

This study demonstrated that it was possible to establish a concise classification system to group patients with meniscal root tears by tear morphology. In this current study, meniscal root tears were grouped into 5 distinct groups: partial stable root tears (type 1), complete radial tears within 9 mm from the root attachment (type 2), bucket-handle tears with root detachment (type 3), complex oblique or longitudinal tears extending into the root attachment (type 4), and bony avulsion fractures of the root attachments (type 5). In addition, complete posterior lateral meniscal root tears in which the meniscofemoral ligament(s) remained intact were classified as a variant of the tear patterns in this classification system.

REFERENCES

1. Allaire R, Muriuki M, Gilbertson L, Harner CD. Biomechanical consequences of a tear of the posterior root of the medial meniscus: similar to total meniscectomy. *J Bone Joint Surg Am*. 2008;90:1922-1931.
2. Barenius B, Ponzer S, Shalabi A, Bujak R, Norlén L, Eriksson K. Increased risk of osteoarthritis after anterior cruciate ligament reconstruction: a 14-year follow-up study of a randomized controlled trial. *Am J Sports Med*. 2014;42(5):1049-1057.
3. Bhatia S, LaPrade CM, Ellman MB, LaPrade RF. Meniscal root tears: significance, diagnosis, and treatment. *Am J Sports Med*. 2014; 42(12):3016-3030.
4. Bin S, Kim J, Shin S. Radial tears of the posterior horn of the medial meniscus. *Arthroscopy*. 2004;20(4):373-378.
5. Brody JM, Lin HM, Hulstyn MJ, Tung GA. Lateral meniscus root tear and meniscus extrusion with anterior cruciate ligament tear. *Radiology*. 2006;239(3):805-810.
6. Choi SH, Bae S, Ji SK, Chang MJ. The MRI findings of meniscal root tear of the medial meniscus: emphasis on coronal, sagittal and axial images. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(10):2098-2103.
7. De Smet AA, Blankenbaker DG, Kijowski R, Graf BK, Shinki K. MR diagnosis of posterior root tears of the lateral meniscus using arthroscopy as the reference standard. *AJR Am J Roentgenol*. 2009; 192(2):480-486.
8. Ellman MB, James EW, LaPrade CM, LaPrade RF. Anterior meniscus root avulsion following intramedullary nailing for a tibial shaft fracture [published online March 19, 2014]. *Knee Surg Sports Traumatol Arthrosc*. doi:10.1007/s00167-014-2941-5
9. Feucht MJ, Grande E, Brunhuber J, Rosenstiel N, Burgkart R, Imhoff AB, Braun S. Biomechanical comparison between suture anchor and transtibial pull-out repair for posterior medial meniscus root tears. *Am J Sports Med*. 2014;42(1):187-193.
10. Feucht MJ, Minzlaff P, Saier T, Lenich A, Imhoff AB, Hinterwimmer S. Avulsion of the anterior medial meniscus root: case report and surgical technique [published March 1, 2013]. *Knee Surg Sports Traumatol Arthrosc*. doi:10.1007/s00167-013-2462-7
11. Forkel P, Herbort M, Schulze M, Rosenbaum D, Kirstein L, Raschke M, Petersen W. Biomechanical consequences of a posterior root tear of the lateral meniscus: stabilizing effect of the meniscofemoral ligament. *Arch Orthop Trauma Surg*. 2013;133(5):621-626.
12. Harner CD, Mauro CS, Lesniak BP, Romanowski JR. Biomechanical consequences of a tear of the posterior root of the medial meniscus: surgical technique. *J Bone Joint Surg Am*. 2009;91(2):257-270.
13. Hutchinson ID, Moran CJ, Potter HG, Warren RF, Rodeo SA. Restoration of the meniscus: form and function. *Am J Sports Med*. 2014;42(4):987-998.
14. Hwang B, Kim S, Lee S, Lee H, Lee C, Hunter DJ, Jung K. Risk factors for medial meniscus posterior root tear. *Am J Sports Med*. 2012;40:1606-1610.
15. Johannsen AM, Civitarese DM, Padalecki JR, Goldsmith MT, Wijdicks CA, LaPrade RF. Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci. *Am J Sports Med*. 2012;40(10):2342-2347.
16. Jung YH, Choi NH, Oh JS, Victoroff BN. All-inside repair for a root tear of the medial meniscus using a suture anchor. *Am J Sports Med*. 2012;40(6):1406-1411.
17. Kennedy NI, Michalski MP, Engebretsen L, LaPrade RF. Iatrogenic meniscus posterior root injury following reconstruction of the posterior cruciate ligament: a report of three cases. *J Bone Joint Surg Case Connect*. 2014;4(1):e20.1-6.
18. Kim JH, Chung JH, Lee DH, Lee YS, Kim JR, Ryu KJ. Arthroscopic suture anchor repair versus pullout suture repair in posterior root

tear of the medial meniscus: a prospective comparison study. *Arthroscopy*. 2011;27(12):1644-1653.
19. LaPrade CM, Ellman MB, Rasmussen MT, James EW, Wijdicks CA, Engebretsen L, LaPrade RF. Anatomy of the anterior root attachments of the medial and lateral menisci: a quantitative analysis. *Am J Sports Med*. 2014;42(10):2386-2392.
20. LaPrade CM, James EW, Engebretsen L, LaPrade RF. Anterior medial meniscal root avulsions due to malposition of the tibial tunnel during anterior cruciate ligament reconstruction: two case reports. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(5):1119-1123.
21. LaPrade CM, Jansson KS, Dornan G, Smith SD, Wijdicks CA, LaPrade RF. Altered tibiofemoral contact mechanics due to lateral meniscus posterior horn root avulsions and radial tears can be restored with in situ pull-out suture repairs. *J Bone Joint Surg Am*. 2014;96(6):471-479.
22. Lee JH, Lim YJ, Kim KB, Kim KH, Song JH. Arthroscopic pullout suture repair of posterior root tear of the medial meniscus: radiographic and clinical results with a 2-year follow-up. *Arthroscopy*. 2009;25(9):951-958.
23. Marzo JM, Gurske-DePerio J. Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. *Am J Sports Med*. 2009;37(1):124-129.
24. Matheny LM, Ockuly AC, Steadman JR, LaPrade RF. Posterior meniscus root tears: associated pathologies to assist as diagnostic tools. [published online May 28 2014]. *Knee Surg Sports Traumatol Arthrosc.* doi:10.1007/s00167-014-3073-7
25. McDermott I. Meniscal tears, repairs and replacement: their relevance to osteoarthritis of the knee. *Br J Sports Med*. 2011;45(4):292-297.
26. Navarro-Holgado P, Cuevas-Perez A, Aguayo-Galeote MA, Carpintero-Benitez P. Anterior medial meniscus detachment and anterior cruciate ligament tear. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(5):587-590.
27. Ozkoc G, Circi E, Gonc U, Irgit K, Pourbagher A, Tandogan RN. Radial tears in the root of the posterior horn of the medial meniscus. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:849-854.
28. Padalecki JR, Jansson KS, Smith SD, Dornan GJ, Pierce CM, Wijdicks CA, LaPrade RF. Biomechanical consequences of a complete radial tear adjacent to the medial meniscus posterior root attachment site: in situ pull-out repair restores derangement of joint mechanics. *Am J Sports Med*. 2014;42(3):699-707.
29. Pengas IP, Assiotis A, Nash W, Hatcher J, Banks J, McNicholas MJ. Total meniscectomy in adolescents: a 40-year follow-up. *J Bone Joint Surg Br*. 2012;94(12):1649-1654.
30. Pula DA, Femia RE, Marzo JM, Bisson LJ. Are root avulsions of the lateral meniscus associated with extrusion at the time of acute anterior cruciate ligament injury? a case control study. *Am J Sports Med*. 2014;42(1):173-176.
31. Schillhammer CK, Werner FW, Scuderi MG, Cannizzaro JP. Repair of lateral meniscus posterior horn detachment lesions: a biomechanical evaluation. *Am J Sports Med*. 2012;40(11):2604-2609.
32. Shelbourne KD, Gray T. Results of anterior cruciate ligament reconstruction based on meniscus and articular cartilage status at the time of surgery: five- to fifteen-year evaluations. *Am J Sports Med*. 2000;28(4):446-452.
33. Stein T, Mehling AP, Welsch F, von Eisenhart-Rothe R, Jäger A. Long-term outcome after arthroscopic meniscal repair versus arthroscopic partial meniscectomy for traumatic meniscal repairs. *Am J Sports Med*. 2010;38(8):1542-1548.
34. Toy JO, Feeley BT, Gulotta LV, Warren RF. Arthroscopic avulsion repair of a pediatric ACL with an anomalous primary insertion into the lateral meniscus. *HSS J*. 2011;7(2):190-193.