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연골판 형태에 따른 완전형 외측 원판형 연골판의 특징적인 파열 양상

Complete Discoid Lateral Meniscus has a Distinct Tear Pattern Depending on Meniscal Morphology

울 산 대 학 교 대 학 원

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지 도 교 수 김 종 민

이 논문을 의학석사 학위 논문으로 제출함

2024년 02월

울 산 대 학 교 대 학 원

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2024년 02월

영문요약

Background: For complete discoid lateral meniscus (CDLM), the pattern and distribution of tears is not well documented in literature.

Purpose: To investigate the prevalence and pattern of meniscal tear types in CDLM using Magnetic Resonance Imaging (MRI) and arthroscopic data from a high-volume tertiary center.

Methods: A consecutive series of 1219 patients (1406 knees) who underwent arthroscopic knee surgery for any pathology and were diagnosed with discoid lateral meniscus (DLM) between January 1998 and December 2022 were retrospectively reviewed. After excluding cases with incomplete DLM (774 knees) and previous history of ipsilateral knee surgery (55 knees), a total of 486 patients (577 knees) with CDLM were evaluated. Mean patient age was 37.4 years (range 5-76 years). Preoperative MRI and intraoperative arthroscopic findings were analyzed to classify tears into the following: peripheral tear (including bucket handle tear), horizontal tear, radial tear, flap tear, and no tear. In addition, preoperative MRI was used to categorize two distinct morphological variants of CDLM: a “block” shaped type with a thick blunt free edge, and a “wedge” shaped type with a tapering sharp free edge.

Results: When categorized by meniscal morphology, 435 knees (75.4%) were classified as block type and 142 knees (24.6%) as wedge type complete DLM. Peripheral tears (66.7%) were the most prevalent in the block type, followed by horizontal tears (22.5%) and radial tears (0.7%). In the wedge type, horizontal tears (43.0%) were observed most frequently, followed by radial tears (18.3%), peripheral tears (11.3%) and flap tears (5.6%).

Conclusion: A block shaped morphology was the predominant form of CDLM. Peripheral tears were the most prevalent in this block type. Wedge type had a distinctly different tear pattern, with horizontal tears being the most common. While block type exhibited either a peripheral or horizontal tear, wedge type was characterized by a greater variation in tear pattern.

Study Design: Case series

Key terms: Discoid Lateral Meniscus, Meniscal Tear, Tear Pattern, Peripheral Tear

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Introduction

Discoid lateral meniscus (DLM) involves both structural and morphological anomalies[1)], and its incidence is estimated at between 0.4% and 17% depending on the studied population[2-8)]. There is a wide-ranging spectrum of clinical manifestations[9)]. DLM can often be asymptomatic, but symptoms can occur at any age[10)]. Variability is also present in its morphology, from nearly normal looking meniscus with minimal differences in width and height, to conspicuously thickened and displaced abnormal menisci[2,11)]. In particular, pediatric patients with complete discoid lateral meniscus (CDLM) have been reported to be 4.5 times more likely to require surgical intervention compared to incomplete DLM[12)], highlighting the role that meniscal morphology may play in the pathophysiology of DLM.

Traditionally, the Watanabe classification has been widely adopted and used. This system delineates three types of discoid lateral meniscus: complete, characterized by a full disk morphology covering the entire tibial plateau; incomplete, denoting increased width but retaining a semilunar shape; and Wrisberg ligament variant, featuring a lateral meniscus that is either normal or thickened but lacks peripheral attachments of the posterior horn, being stabilized posteriorly solely by the Wrisberg meniscofemoral ligament.[13)] However, this classification has shown incompatibility with factors such as concomitant meniscal tears, meniscal shift, and abnormal height or thickness[14-16)]. Consequently, various authors have proposed additional classification systems that are based on peripheral rim instability and presence or absence of meniscal tears[17-19)]. A more recently developed classification system has been introduced by the Pediatric Research in Sports Medicine (PRiSM) organization. This classification system focuses on four key elements of DLM: meniscal width, meniscal height, peripheral stability, and meniscal tear. Width is categorized as W0 to W2, representing normal to near-complete coverage of the plateau (>90%, respectively). Height is denoted as H0 for normal height and H1 for thickness exceeding normal. Stability is classified as S0 (no instability), SA (anterior half instability), SP (posterior half instability), and SAP (both anterior and posterior instability). Regarding tear classification, T0 signifies the absence of tears. THA/THP refer to horizontal tears in the anterior or posterior meniscus, while THAP describes a horizontal tear spanning both anterior and posterior tissues. TDA/TDP/TDAP denote the same anatomic locations with degenerative, complex, or radial tearing[16)]. Despite the descriptive nature of these classification systems, none have thus far demonstrated the capability to prognosticate the natural history or surgical outcomes associated with discoid lateral menisci.

While previous studies have shown that complete and incomplete DLM have significant differences in tear pattern[20,21)], the literature specifically addressing tear distribution of CDLM remains notably absent. The current study aims to bridge this gap by investigating the prevalence and pattern of meniscal tear types in patients with CDLM utilizing a comprehensive dataset comprising Magnetic Resonance Imaging (MRI) and arthroscopic findings from a high-volume tertiary center. We hypothesize that a difference in morphology of the CDLM will be associated with a difference in tear pattern.

Methods

The medical records, radiographic studies and arthroscopic imaging data of all consecutive patients who underwent arthroscopic knee surgery for any pathology and were diagnosed with discoid lateral meniscus between January 1998 and December 2022 were reviewed. The inclusion criteria were (1) confirmed intra-operative diagnosis of complete discoid lateral meniscus; (2) availability of pre-operative knee magnetic resonance imaging (MRI) and intra-operative arthroscopic images; and (3) no previous history of ipsilateral knee surgery. Institutional review board approval was obtained.

1219 patients (1406 knees) were identified, and after excluding cases with incomplete discoid lateral meniscus (774 knees) and previous history of ipsilateral knee surgery (55 knees), a total of 486 patients (577 knees) with CDLM were included in this study (Figure 1). Mean age at the time of surgery was 37.4±17.5 years (range, 5-76 years). There were 158 male (182 knees) and 328 female patients (395 knees). Surgery was performed on 280 right knees and 297 left knees. 91 patients received surgery for bilateral DLM. (Table 1)

The location, size, and shape of meniscal tears were systematically assessed during arthroscopic examination. Based on the arthroscopic findings, tears were classified into peripheral tears, horizontal tears, radial tears, flap tears, and no tear. Bucket handle tears were included into peripheral tears, as they represent an unstable and displaced peripheral tear.

In addition, preoperative MRI was used categorize two distinct morphological variants of CDLM: a "Block" shaped type with a thick central portion and blunt free edge, and a "Wedge" shaped type with a tapering central portion and sharp free edge. This morphologic variation was best observed on coronal sequence MRI images through the midbody portion of the meniscus (Figure 2).

To evaluate intra-observer and inter-observer reliability, 50 knees were selected randomly, and the analysis was repeated by two clinical orthopedic fellows at an interval of 1 month.

Statistical analysis was performed to determine any significant differences in categorical variables between the different groups. Fisher's exact test and paired t test were used as appropriate. A p value of <0.05 was considered statistically significant. Data analysis was carried out using Statistical Package for the Social Sciences (SPSS) software (IBM Corp. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY).

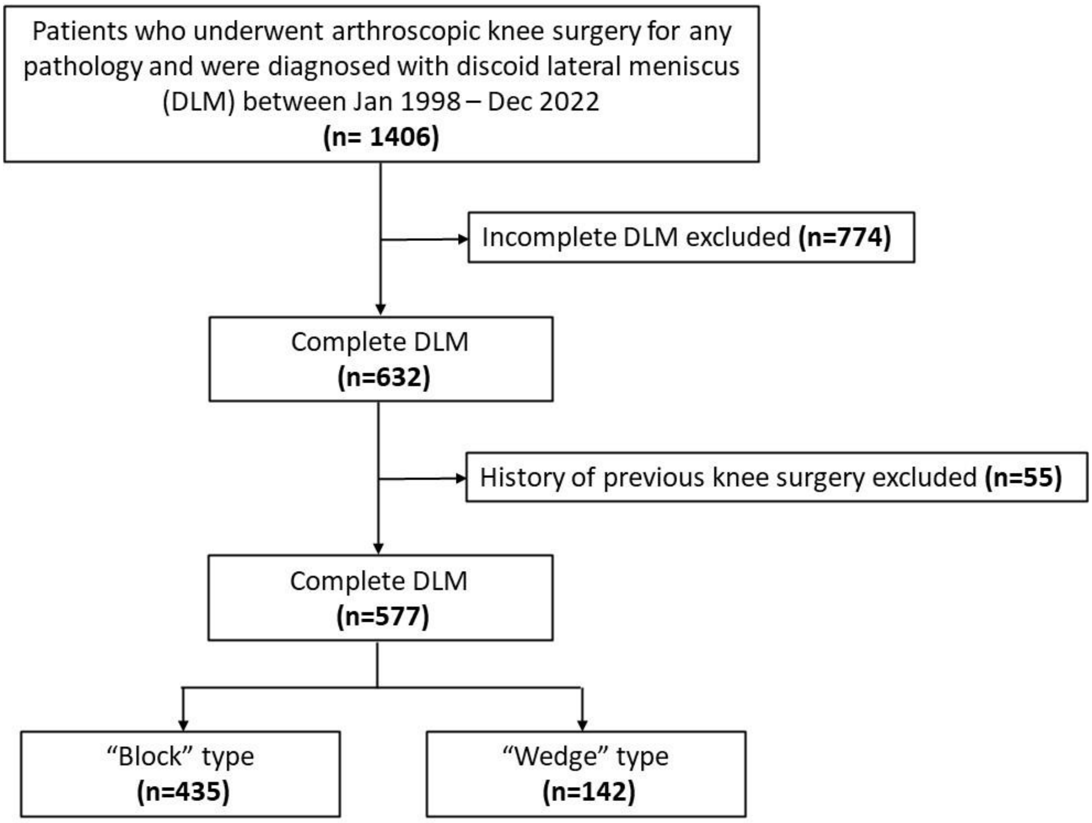

Figure 1. Flow chart of patient selection and subgrouping of complete discoid lateral meniscus depending on meniscal morphology.

Table 1. Patient Demographics

Demographics	Total	CDLM type		*p value*
		Block	Wedge	
Male	182(31.5)	139(31.9)	43(30.3)	0.756
Female	395(68.5)	296(68.1)	99(69.7)	
Left	280(48.5)	204(46.9)	76(53.5)	0.177
Right	297(51.5)	231(53.1)	66(46.5)	
Mean age(yrs)	37.4±17.5	35.6±17.6	42.9±16.5	0.821

Values are presented as n(%). CDLM Complete Discoid Lateral Meniscus.
p values were calculated using Fisher's exact test and paired t test

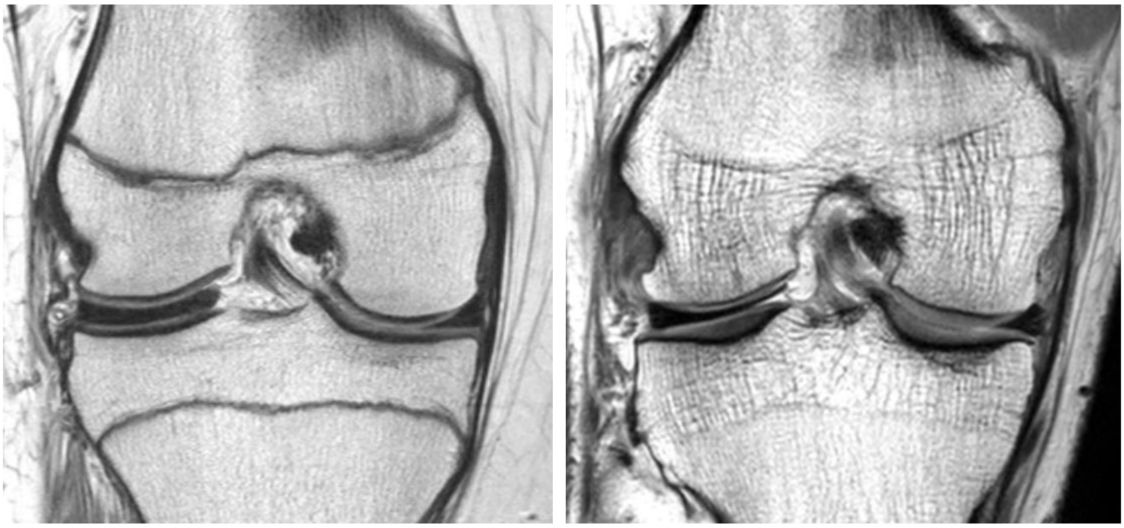

Figure 2. Left image shows MRI coronal section of a 15-year-old female patient's right knee demonstrating "Block" type complete discoid lateral meniscus (CDLM) with a thick blunt free edge. Right image shows 40-year-old male patient's right knee with "Wedge" type CDLM that tapers centrally towards a sharp free edge.

Results

Based on discoid meniscus morphology, 435 knees (75.4%) were classified as block type and 142 knees (24.6%) as wedge type CDLM (Table 2). In the block type, peripheral tears (66.7%) were the most prevalent (Figure 3), followed by horizontal tears (22.5%) and radial tears (0.7%). In the wedge type, horizontal tears (43.0%) were observed most frequently (Figure 4), followed by radial tears (18.3%), peripheral tears (11.3%) and flap tears (5.6%). Additionally, 10.1% of block type and 21.8% of wedge type did not have meniscal tears (Figure 5). There was a statistically significant difference in the tear pattern distribution between the two morphologic variants. Gender, age at the time of surgery, and laterality were not significantly different between the two groups.

In the agreement for the tear pattern and meniscal morphology, intra-class correlation coefficient (ICC) of the inter-observer reliability was 0.904 and 0.912 and intra-observer reliability was 0.984 and 0.930 respectively, indicating high reliability.

Table 2. Meniscal Tear Pattern and Distribution

		CDLM type		
Tear pattern	**Total**	**Block**	**Wedge**	*p value*
Peripheral tear (Including bucket handle tear)	306(53.1)	290(66.7)	16(11.3)	<0.001
Horizontal tear	159(27.6)	98(22.5)	61(43.0)	<0.001
Radial tear	29(5.0)	3(0.7)	26(18.3)	<0.001
Flap tear	8(1.4)	0(0)	8(5.6)	<0.001
No tear	75(12.9)	44(10.1)	31(21.8)	0.001
Total	577	435	142	

Values are presented as n(%). CDLM Complete Discoid Lateral Meniscus

p values were calculated using Fisher's exact test

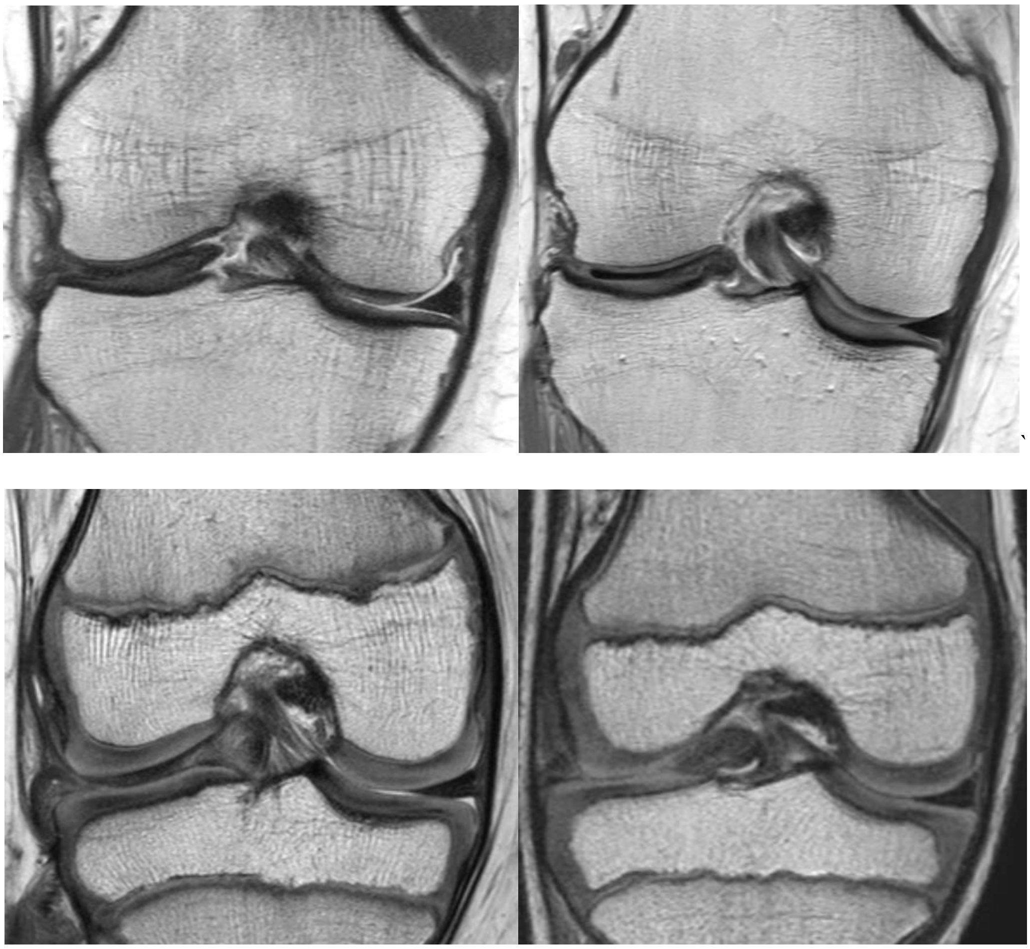

Figure 3. MRI Coronal sequence images of four different patients. Peripheral and bucket handle tears were prevalent in the “Block” type complete discoid lateral meniscus and showed varying amounts of displacement.

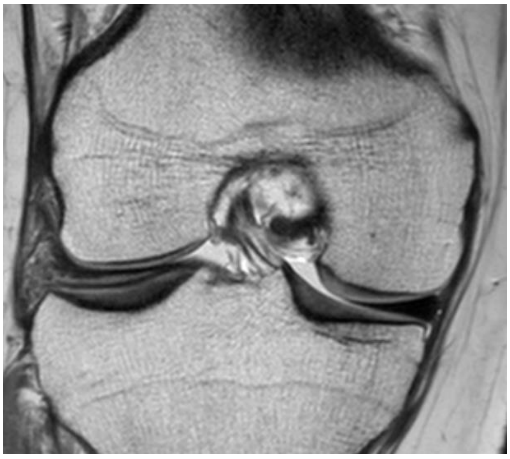

Figure 4. Horizontal tears were the most common tear in the “Wedge” type complete discoid lateral meniscus.

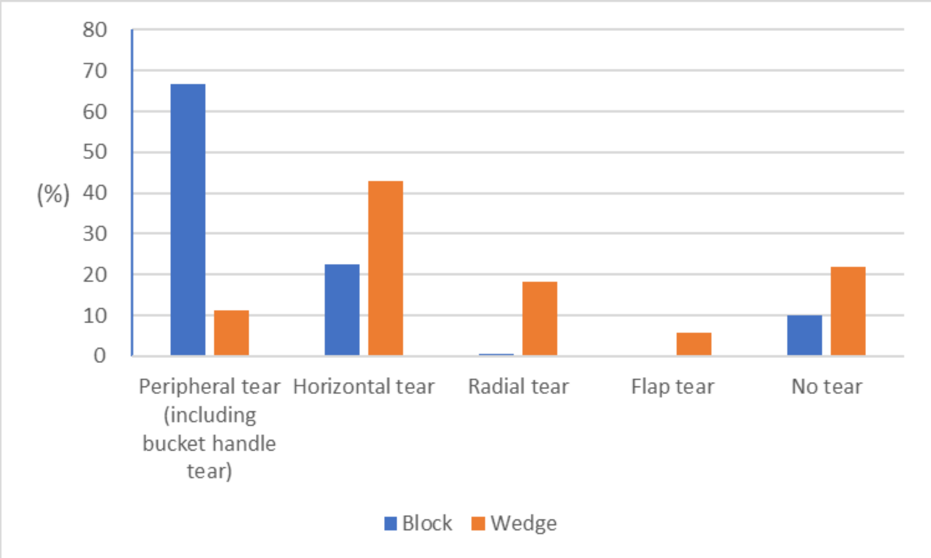

Figure 5. Bar graphs depicting the distribution of tear type in "Block" and "Wedge" type complete discoid lateral meniscus.

Discussion

The most important finding of this study was that CDLM follows a distinct tear pattern depending on meniscal morphology. Notably, we observed that the block-shaped morphology predominated with 75.4%, while the wedge-shaped morphology accounted for the remaining 24.6%.

In block type DLM, peripheral tears were overwhelmingly prevalent, constituting 66.7% of observed tears, followed by horizontal tears at 22.5%, and other tear types were negligible. In contrast, wedge type DLM exhibited a noticeably more diverse and varied tear pattern, with horizontal tears being the most common at 43.0%, followed by radial tears (18.3%), peripheral tears (11.3%), and flap tears (5.6%). This dichotomy in tear patterns suggests that the structural differences between these morphological variants may influence the biomechanical stress distribution and susceptibility to specific types of tears. Bin et al reported that the extent of meniscal resection in DLM tears was dependent on the tear pattern, and that subtotal or total meniscectomy was performed significantly more frequently in longitudinal/peripheral tears[20]. Thus, block type complete DLM with its higher prevalence of peripheral tears can be assumed to be at higher risk for increased meniscal resection when receiving surgical treatment.

The meniscus plays a crucial role in enhancing load distribution within the tibiofemoral joint, thereby facilitating greater contact area and reduced contact pressures. This phenomenon is particularly noteworthy in the lateral compartment, wherein 70% of the load is transmitted to the lateral meniscus, as opposed to 50% in the medial compartment. This discrepancy is attributed to the substantial contribution of the lateral meniscus to joint congruity. The significance of the meniscus in load distribution is underscored by the findings of Ahmed and Burke, whose study indicated a substantial 50–70% decrease in contact area and a subsequent increase in contact pressures subsequent to medial meniscectomy.[22)]

A myriad of contemporary laboratory studies have delved into the ramifications of various meniscal pathologies on the biomechanics, kinetics, and kinematics of the knee joint. These studies collectively contribute to a comprehensive understanding of how alterations in meniscal integrity can impact the mechanical aspects of knee function.[23)]

Longitudinal meniscal tears, characterized by their parallel orientation to the circumferential extracellular matrix fibers, generally exhibit a lower propensity to impede the biomechanical function of the meniscus. These tears typically do not compromise the meniscus' capacity to convert axial loads into hoop stresses. A cadaveric study conducted by Goyal et al. exemplifies this point, revealing no discernible disparity in contact pressures between specimens featuring an intact lateral meniscus and those with an artificially induced longitudinal tear.[24)]

Nevertheless, it is crucial to acknowledge that the impact of tears may vary within distinct regions of the meniscus. In particular, longitudinal tears in the horns of the meniscus can present heightened challenges. A recent finite element analysis study by Zhang et al. underscored the biomechanical repercussions of longitudinal tears at the horns, indicating an elevation in peak compressive and shear stresses on the menisci, cartilage, and subchondral bone under both static and dynamic-flexion simulations[25]. Notably, the study emphasized more pronounced biomechanical alterations following tears in the medial meniscus and tears in the posterior horn. This observation finds support in the findings of Chen et al., whose cadaveric study demonstrated compromised contact pressure subsequent to longitudinal tearing of the medial meniscus.[26]

Similar to longitudinal tears, horizontal cleavage tears do not disrupt the circumferential arrangement of collagen fibers within the meniscus. However, despite this shared characteristic, horizontal cleavage tears are associated with a higher degree of correlation with altered biomechanics. In a cadaveric study conducted in 2017 by Beamer et al., it was reported that horizontal cleavage tears led to a substantial 70% increase in contact pressures across all flexion angles.[27] Moreover, when addressing this tear pattern through partial meniscectomy, previous studies have indicated noteworthy outcomes. Specifically, in cases where one medial meniscal leaflet was resected, contact pressures increased by 33–46%. The impact was even more pronounced when both leaflets were excised, resulting in a remarkable elevation of pressure by 75–79%.[28,29]

Radial tears, characterized by their perpendicular extension across the circumferential collagen fibers, have the potential to compromise the meniscus' ability to convert loads into hoop stresses. Particularly, large radial tears and root tears share functional equivalence with a total meniscectomy, as they fully disrupt the meniscus' circumferential collagen fibers, resulting in the functional failure of the meniscus.[30] In contrast, partial radial tears allow for the retention of a certain degree of the meniscus' inherent biomechanical function. Cadaveric studies have provided valuable insights, indicating that partial tears, extending up to 60–66% of the meniscal width, have minimal to no impact on the meniscus' load-dissipating properties.[31,32]

The meniscus assumes a pivotal role in governing physiologic in vivo knee kinematics. A wealth of evidence attests to the notable impact on knee kinematics resulting from compromised meniscal function. In a study conducted by Zhang et al., an exploration of gait kinematics in patients with ACL deficiency, both with and without concurrent meniscal injuries, revealed a discernible impairment in physiological knee kinematics.[33] Notably, the deviation from normal knee function was contingent upon the location of the meniscal tear. Individuals presenting with concomitant tears in both the medial and lateral menisci exhibited aberrant sagittal excursion, particularly in anterior tibial translation. Conversely, those with an isolated medial meniscus tear displayed a marked increase in lateral tibial translation. These findings were corroborated by Hosseini et al., who, in a dynamic fluoroscopy-based assessment during stair-climbing, reported analogous observations.[34] Furthermore, an additional investigation employing three-dimensional gait analysis demonstrated a significant elevation in axial plane rotation angles throughout the entire gait cycle among patients with concomitant unstable meniscus tears compared to those with isolated ACL tears.[35] These collective findings underscore the critical role of the meniscus in preserving normal knee kinematics and highlight the distinct kinematic alterations associated with various patterns of meniscal injury.

The presence of discoid lateral menisci has been identified as a factor contributing to altered kinematics, as evidenced by gait analyses conducted by Li et al.[36] Their research demonstrated notable variations in knee kinematics in individuals with a discoid meniscus. Specifically, patients with a discoid meniscus exhibited significantly lower peak knee flexion angles during both stance and swing phases, accompanied by reduced adduction-abduction angles throughout the gait cycle. This pattern of restricted knee excursion was consistently observed when comparing discoid meniscus groups to healthy controls and when contrasting symptomatic discoid menisci with asymptomatic counterparts. In contrast to the characteristic external rotation during stance and internal rotation during the swing phase in healthy knees, individuals with discoid menisci displayed decreased internal rotation during the swing phase. This deviation from normal knee kinematics suggests a distinctive impact associated with discoid menisci. Lin et al. put forth the hypothesis that the resultant non-physiological horizontal shear stress may initiate structural degradation of the meniscus.[37] These results indicate the significance of discoid lateral menisci in influencing knee kinematics and highlight the potential consequences of such alterations, implicating the initiation of structural compromise within the meniscus.

Histological studies have shown irregularly oriented collagen fibers in discoid lateral meniscus[38-40]. Papadopoulos et al demonstrated the marked disorganization and heterogenous course of the circumferentially arranged collagen network in DLM compared to the normal meniscus[41]. Such a distorted anatomy may hinder the meniscus' ability to absorb load and dissipate hoop stress effectively and be more susceptible to injury. Moreover, the disorganized collagen matrix may not function as efficiently in serving as a scaffold to hole the glycosaminoglycans necessary for normal meniscal function[38]. Differences in both the microstructure (collagen network) and macrostructure (meniscus morphology) may contribute to the variation in tear pattern[40].

A recently developed DLM classification system from the PRISM group distinguished between normal and abnormal meniscal height, although the authors did not discuss what implications the difference in height may entail[16,42]. Our study sheds light on the ramifications of DLM with markedly increased height, as this can be considered an equivalent of the block type. Meniscal height is a key characteristic of DLM that has until now been neglected in most classification systems[15,17,18], and the proposed binary distinction is a simple and effective method to categorize this morphologic variation.

There was an absence of tears in 10.1% of block type and 21.8% of wedge type complete DLM. These patients were diagnosed with DLM incidentally while receiving treatment for a different pathology of the knee such as ligament injury or medial meniscal tears. A higher proportion of wedge type DLM with no tears suggests that this variant may remain asymptomatic in a larger portion of the population, while block type is more likely to cause symptoms. However, determining the true incidence of DLM and the prevalence of symptomatic DLM remains elusive[43,44].

The findings of this study underscore the importance of preoperative MRI evaluation for characterizing DLM morphology, as it can aid in surgical planning by providing a roadmap for expected tear patterns. The ability to anticipate tear types based on meniscal morphology may contribute to more tailored surgical approaches and personalized treatment strategies.

The results of this study demonstrate that in the majority of cases, block type CDLM is torn in one of two ways: horizontal tear and peripheral tear. Cho et al reported that horizontal tears of DLM, even if left untreated and observed, often do not lead to significant cartilage damage for an extended period of time compared to other types of tears, suggesting a relatively benign prognosis[45]. However, peripheral tears can be displaced early, with a potential risk of accelerated cartilage wear. Further research focusing on the clinical outcomes of peripheral tears of CDLM will be necessary to gain additional insight.

This study has a number of limitations. The retrospective nature of the study may introduce bias and confounding variables that were not controlled for during initial data collection. Additionally, the study was conducted at a single high-volume tertiary center, which may limit the generalizability of the results due to the study population not being representative of the broader population. Also, the definitions for block and wedge type are not based on objective and precise measurements, but rather are of a descriptive nature. However, we believe that this is an intuitive and easily usable method that has shown high intra- and inter-observer reliability.

Conclusion

A block shaped morphology was the predominant form of complete DLM. Peripheral tears were the most prevalent in this block type. Wedge type had a distinctly different tear pattern, with horizontal tears being the most common. While block type exhibited either a peripheral or horizontal tear, wedge type was characterized by a greater variation in tear pattern.

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국문 요약

배경: 기존 문헌에는 완전형 외측 원반형 연골판의 파열 양상 및 분포에 대한 명확한 보고가 없다.

연구목적: 완전형 외측 원반형 연골판으로 진단을 받은 환자군의 자기공명영상검사(MRI)와 관절경 영상 자료를 분석하여 원반형 연골판 파열의 빈도, 분포 및 특성을 조사하였다.

방법: 1998년 1월부터 2022년 12월 사이 단일기관에서 슬관절에 대한 관절경 수술을 시행하고 외측 원반형 연골판을 진단 받은 일련의 환자 1,219명의 1,406무릎을 후향적으로 검토하였다. 이 중에서 불완전형 외측 원반형 연골판으로 진단받은 무릎 774례와 이전 환측 슬관절 수술력이 있는 무릎 55례를 제외하여, 최종적으로 완전형 외측 원반형 연골판을 진단받은 환자 486명의 577무릎을 대상으로 연구하였다. 환자 평균 연령은 37.4세(범위 5-76세) 였다. 수술 전 촬영한 자기공명영상검사와 수술 중 획득한 관절경 영상 및 사진을 분석하여 연골판 파열을 다음과 같이 분류하였다: 변연부 파열, 수평 파열, 방사형 파열, 판상 파열, 파열 없음. 또한, 자기공명영상에서 보여지는 형태에 따라 완전형 외측 원반형 연골판을 두 유형으로 분류하였으며, 내부가 전반적으로 두꺼운 ‘블록형’과 내부과 점차 가늘어지는 ‘쐐기형’으로 명명하였다.

결과: 연골판 형태에 따라 나누었을 때 435무릎(75.4%)은 블록형으로, 142무릎(24.6%)은 쐐기형으로 분류되었다. 블록형에서는 변연부 파열(66.7%)이 가장 많았으며, 수평 파열(22.5%)과 방사형 파열(0.7%)이 그 뒤를 이었다. 쐐기형에서는 수평 파열(43.0%)이 가장 흔하였고, 이후 방사형 파열(18.3%), 변연부 파열(11.3%), 판상 파열(5.6%) 순이었다.

결론: 완전형 외측 원반형 연골판의 주된 형태는 블록형 이었으며, 이 블록형에서는 변연부 파열이 가장 흔히 관찰되었다. 쐐기형은 이와 유의미하게 다른 연골판 파열 분포를 보였고, 수평 파열이 가장 많았다. 블록형은 변연부 또는 수평 파열을 보인 반면, 쐐기형은 보다 다양한 양상의 파열이 관찰되었다.