

Original Article

Biomechanical differences before and after arthroscopic partial meniscectomy in patients with semilunar and discoid lateral meniscus injury

Yaqiang Li^{1,3}, Yu Wu^{2,3}, Yiming Zeng¹, Dongyun Gu^{1,2,3}

¹Shanghai Key Laboratory of Orthopaedic Implants, Department of Orthopaedic Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200011, China; ²School of Biomedical Engineering & Med-X Research Institute, Shanghai Jiao Tong University, Shanghai 200030, China; ³Engineering Research Center of Digital Medicine and Clinical Translation, Ministry of Education of People's Republic of China, Shanghai 200030, China

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Abstract: The purpose of the current study was to investigate the differences in knee kinematics and kinetics in patients with semilunar lateral meniscus (SLM) and discoid lateral meniscus (DLM) injuries before and after arthroscopic partial meniscectomy during level walking. Fifteen healthy volunteers (control group), thirteen patients with SLM injury (SLM group) and nine patients with DLM injury (DLM group) were enrolled in our study. Gait analyses were performed pre- and post-operatively during level walking at a self-selected walking speed. Our results showed that compared to the control group before surgery, the SLM and DLM groups showed significantly lower walking speed, shorter stride length, lower maximum knee flexion during stance phase and swing phase, lower first peak knee flexion moment, and smaller adduction-abduction range of motion (ROM) during the gait cycle. Compared to the control group, only the DLM group showed significantly decreased flexion-extension ROM and maximum abduction angle. The first peak knee adduction moment was lower in the SLM group than in the control group. Significant difference was observed in first peak knee flexion moment between SLM and DLM groups. After surgery, there were no significant differences in gait spatiotemporal parameters, knee kinematics, and kinetics between the three groups, indicating that meniscectomy is an effective treatment for both types of injury. By using three-dimensional gait analysis, the current results revealed that lateral meniscus types influence gait patterns after injury, which may further impact clinical treatment choice and long-term prognosis.

Keywords: Arthroscopic partial meniscectomy, discoid lateral meniscus, kinematics, kinetics, biomechanics

Introduction

Discoid lateral meniscus (DLM) is a common anatomical variant of the lateral meniscus, with lower incidence (0.4% to 5%) in Europe and higher incidence (9.1% to 17%) in Asia [1, 2]. Morphologically, compared to semilunar lateral meniscus (SLM), DLM is thicker and discoid-shaped. Histologically, collagen fibers in DLM are disorganized and less in number, thus increasing the vulnerability of the meniscus to injury [3]. Disorganization of the circular collagen fiber system in the DLM matrix may contribute to the pathogenesis of tear and development of degenerative lesions [2]. Indeed, it has been shown that lateral meniscus degeneration and tears occur more often in DLM than in SLM [3-5]. Symptomatic DLM with clinical evi-

dence of tears or instability usually requires arthroscopic partial meniscectomy (APM), which is currently considered as the standard therapy for irreparable torn meniscus [6].

Several *in vitro* studies [7-9] and analytical models [10-13] have shown that meniscectomy increases contact stress due to limited shock absorption and load distribution function of the meniscus. Although these studies suggest that meniscectomy causes increased stress in knee joint, other alterations in dynamic joint activity after partial meniscectomy for DLM remain unknown. Furthermore, because DLM is wider than the normal meniscus, more meniscal tissue may be retained in partial meniscectomy for DLM than for SLM. Typically, the post-operative width of the remaining peripheral rim is

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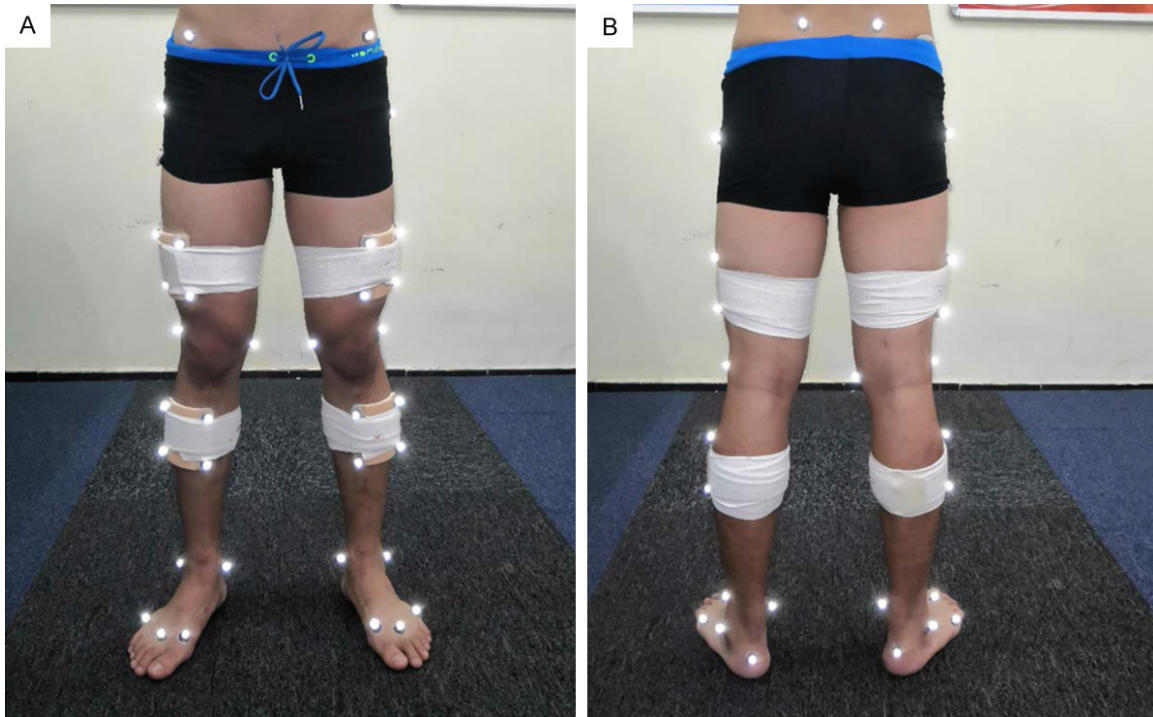


Figure 1. Placement of reflective markers on participants. A. The front view of the placement of markers. B. The back view of the placement of markers.

approximately 4-8 mm, and this residual volume after resection is comparable to that of normal lateral meniscus [14-16]. Therefore, it is unknown whether there is a difference in joint dynamics between patients with DLM injury and those with SLM injury after partial meniscectomy.

The primary aim of the present study was to investigate the three-dimensional (3D) knee kinematics and kinetics during level walking in patients with SLM or DLM injury before and after APM. We hypothesized that the knee mobility limitations and knee loading distribution before surgery would be different between patients with DLM and those with SLM injury. We further hypothesized that after surgery, APM would improve gait restriction in patients with meniscal injury, and patients with DLM injury would present different gait adaptations than patients with SLM injury.

Materials and methods

Participants

This study was approved by the university's ethics committee (No: 2019050) and Chinese Clinical Trial Registry (ChiCTR1900022548). All

participants provided written informed consent prior to enrollment. Twenty-two patients diagnosed with lateral meniscus injury were recruited in this study. Thirteen of the participants were diagnosed with SLM injury (SLM group) and nine with DLM injury (DLM group). The inclusion criteria were: confirmed tear of the lateral meniscus after clinical examination and magnetic resonance imaging (MRI), patients below 40 years of age, no signs of cartilage lesions based on MRI results, no signs of osteoarthritis (OA) in the surgical lower limb, and time from injury to surgery < 3 months. Finally, 15 age-, sex-, and BMI-matched healthy volunteers were recruited as a control group.

Motion analysis testing

Kinematic data sampled at 120 Hz was captured using an eight-camera VICON motion analysis system (Oxford Metrics, Oxford, UK). The ground reaction force sampled at 1080 Hz was recorded using four AMTI force-plates (AMTI, Watertown, MA). 22 reflective markers were attached to the following anatomical landmarks of the participants: the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleo-

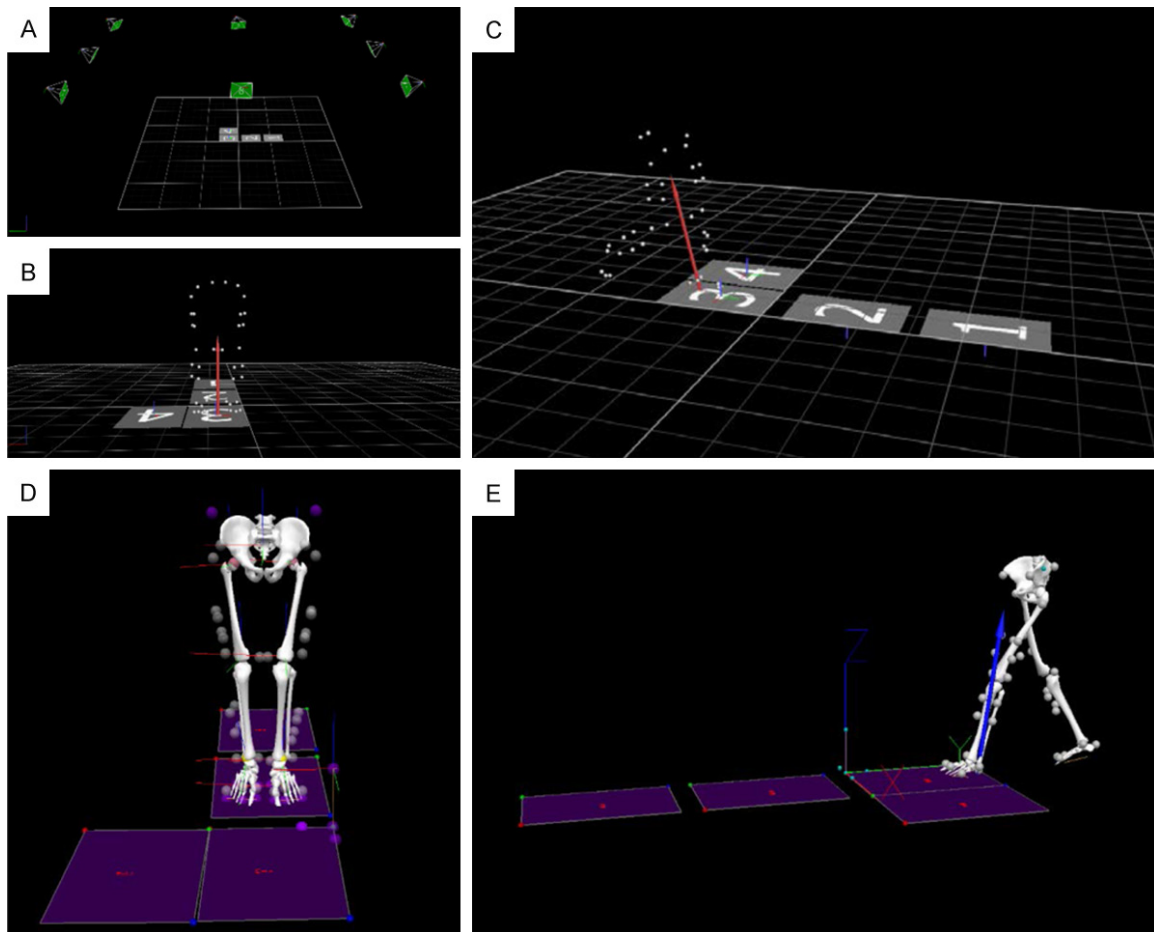


Figure 2. The capture of motion and analysis model for gait experiments. (A) An eight-camera VICON motion analysis system and four AMTI force-plates were used in the present study. Static trial (B) and walking trial (C) in VICON motion analysis system. The static model (D) and walking model (E) in Visual 3D software.

li, posterior calcanei, and the head of the first, second, and fifth metatarsals (**Figure 1**). The four anatomical frames were rigid clusters of four nonorthogonal markers and were placed over the lateral shank and the lateral thigh of the lower limbs (**Figure 1**). A static trial was first conducted as reference to determine the body mass and the center of the joints (**Figure 2**). After the static trial, each patient performed at least five trials of barefoot normal-pace walking on a 10-m walkway with successful force-plate strikes (**Figure 2**). Walking speed was monitored using the TC Timing System (Brower Timing System, UT, USA), and trials were acceptable if the speed was within $\pm 5\%$ of the self-selected speed. Trials were considered acceptable if the patient made contact with the entire foot on the force plate without any noticeable gait deviations. Gait analysis was performed pre-surgery and three months after surgery.

Processing of motion data

The kinematic and kinetic variables were calculated using a multi-segment linked model with a commercially available software (Visual 3D, C-motion Inc., USA) (**Figure 2**) [17]. The pelvic, thigh, shank and foot segments were defined and tracking markers were used for each segment. The 3D positions of markers were used to identify the center of the joints [18]. The mid-points between the malleoli and femoral epicondyles were defined as the ankle and knee joint centers, respectively. The hip joint center was calculated based on the ASIS and PSIS markers according to Bell et al. [19]. The 3D coordinate system was defined according to a previous study [20]: X-axis for the forward/backward, Y-axis for the left/right (medial/lateral), and Z-axis for the vertical. Knee joint moments were calculated using 3D inverse dynamics and normalized to body mass.

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Table 1. Demographic characteristics of the control, SLM and DLM groups

Variable	Control	SLM	DLM	p value
Age (years)	27.1 ± 2.8	29.3 ± 5.8	30.8 ± 6.3	0.227
Males/females (n)	6/9	7/6	4/5	1.000
Height (cm)	168.27 ± 7.09	171.54 ± 7.63	170.44 ± 7.26	0.522
Mass (kg)	68.13 ± 10.00	70.92 ± 11.80	71.22 ± 10.82	0.745
BMI (kg/m ²)	23.99 ± 2.67	23.98 ± 2.93	24.45 ± 3.10	0.920
Lysholm score before surgery	-	78.77 ± 8.79	76.22 ± 9.08	0.537
Lysholm score after surgery	-	88.15 ± 6.49	91.33 ± 7.96	0.338

Statistical analysis

Shapiro-Wilk tests were performed and Q-Q plots were conducted to inspect the normal distribution of all variables. Data were presented as frequencies and as mean and standard deviation (SD) for demographic characteristics and all gait parameters. One-way analysis of variance (ANOVA) and chi-square tests of proportions were used to analyze the demographic characteristics. To demonstrate differences between the three groups, ANOVA followed by Bonferroni multiple comparison tests were performed. The pre- and post-surgery changes were analyzed with paired t tests. Statistical analysis was conducted using SPSS software (Version 20.0, IBM). The level of statistical significance was set at $P < 0.05$.

Results

There were no significant differences in demographic characteristics between individuals. Evaluation of the surgical limbs using the Lysholm score showed that knee function was improved after surgery (**Table 1**). **Figures 3** and **4** show the 3D kinematic and kinetic data of the control, SLM, and DLM groups before and after surgery during a gait cycle. **Tables 2** and **3** show the spatiotemporal, knee kinematic and kinetic parameters.

Spatiotemporal parameters

Before surgery both the SLM and DLM groups showed a significantly slower gait speed ($P = 0.014$ for SLM group; $P = 0.008$ for DLM group) and shorter stride length ($P = 0.017$, SLM group; $P < 0.001$, DLM group) compared to the control group. After surgery, there was a significant increase in walking speed and stride length in the SLM group ($P = 0.027$, walking speed; $P = 0.028$, stride length) and the DLM

group ($P = 0.032$, walking speed; $P = 0.001$, stride length). Although the average walking speed in the SLM group (1.26 ± 0.12 m/s) and the DLM group (1.25 ± 0.13 m/s) remained lower than that of the control group (1.28 ± 0.13 m/s), the differences between the three groups after surgery were not significant. Furthermore, no statistically significant differences were observed between the three groups after surgery in terms of cadence and stride length (**Table 2**).

Kinematics

In the sagittal plane, gait phases in the SLM and DLM groups showed significantly different patterns preoperatively. Both groups had smaller maximum knee flexion angles compared to the control group during the stance and swing phases ($P = 0.033$, SLM and $P < 0.001$, DLM during stance; $P = 0.007$, SLM and $P < 0.001$, DLM during swing). Furthermore, a significantly lower range of motion (ROM) of knee flexion-extension was observed in the DLM group than in the control group during the gait cycle ($P = 0.009$), while no significant difference was found between the SLM group and the control group ($P = 0.229$). After surgery, the kinematics in the sagittal plane significantly improved in both the SLM ($P = 0.023$ for maximum knee flexion during stance phase and $P = 0.010$ for maximum knee flexion during swing phase) and the DLM groups ($P = 0.010$ for maximum knee flexion during stance phase, $P = 0.006$ for maximum knee flexion during swing phase, and $P = 0.044$ for knee flexion-extension ROM), and no difference was observed between the three groups. In the coronal plane, a significantly altered pattern of knee adduction-abduction movement during the gait cycle was observed in the DLM group when compared to the control group. The maximum knee adduction angle

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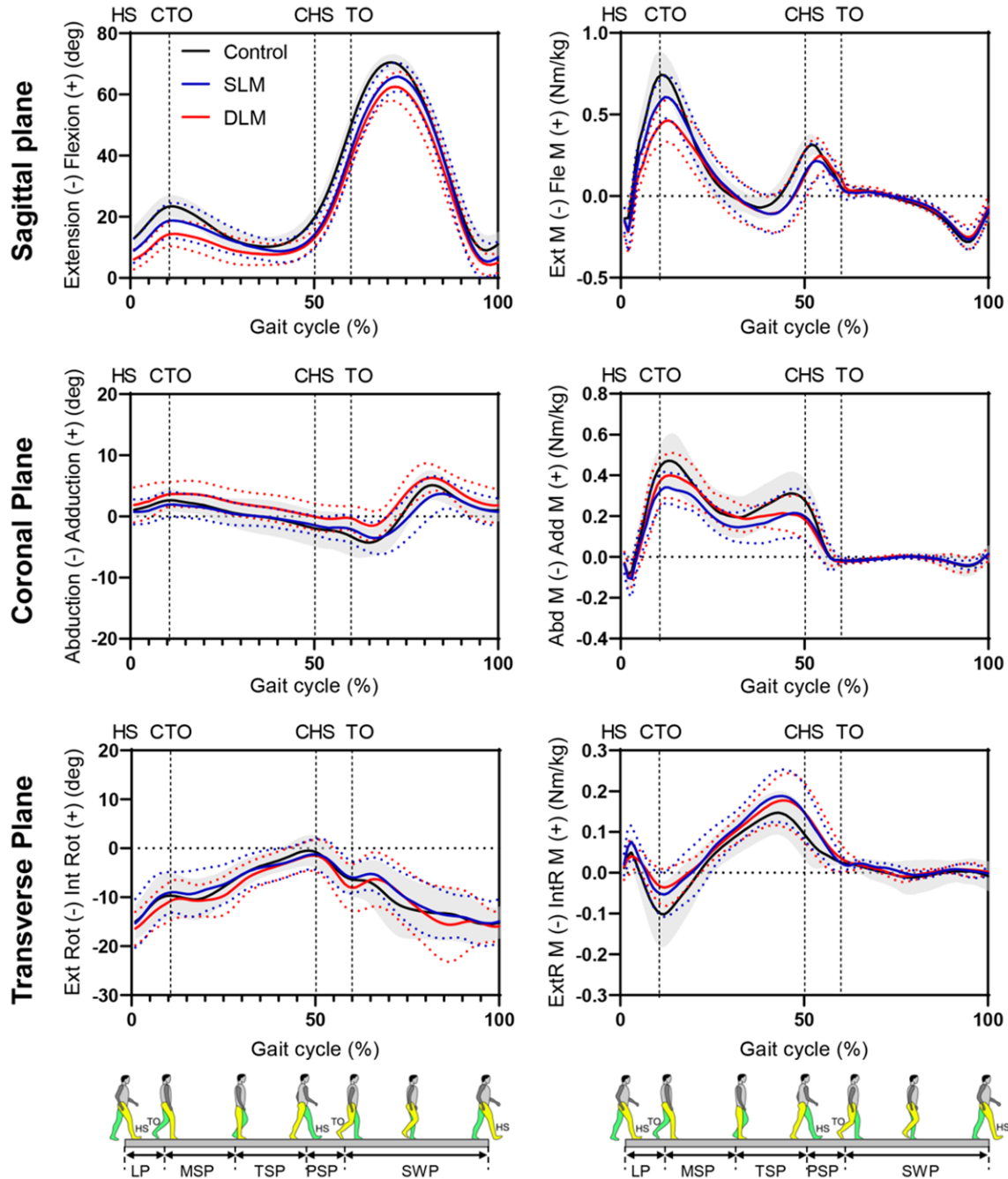


Figure 3. Pre-operative knee kinematics and kinetics of the control group, SLM group, and DLM group in sagittal plane, coronal plane, and transverse plane. The gray shaded area represents SD of the control group. The dotted line above and below the curves represents the SD of the SLM and DLM groups. HS: heel strike, CHS: contralateral heel strike, TO: toe off, CTO: contralateral toe off, LP: loading phase, MSP: midstance phase, TSP: terminal stance phase, PSP: pre-swing phase, SWP: swing phase.

was larger in the DLM group than in the control and SLM groups, albeit without statistical significance ($P = 0.185$ for stance phase and $P = 0.057$ for swing phase). Compared to the control group, patients in the DLM group showed smaller maximum knee abduction angle ($P = 0.001$), and no significant difference was ob-

served between the SLM and DLM groups ($P = 0.070$). Moreover, there was no significant difference in the maximum knee abduction angle between the three groups post-operatively. In the transverse plane, no difference was observed between the three groups either pre- or post-operatively.

Biomechanical differences in patients with SLM and DLM injuries

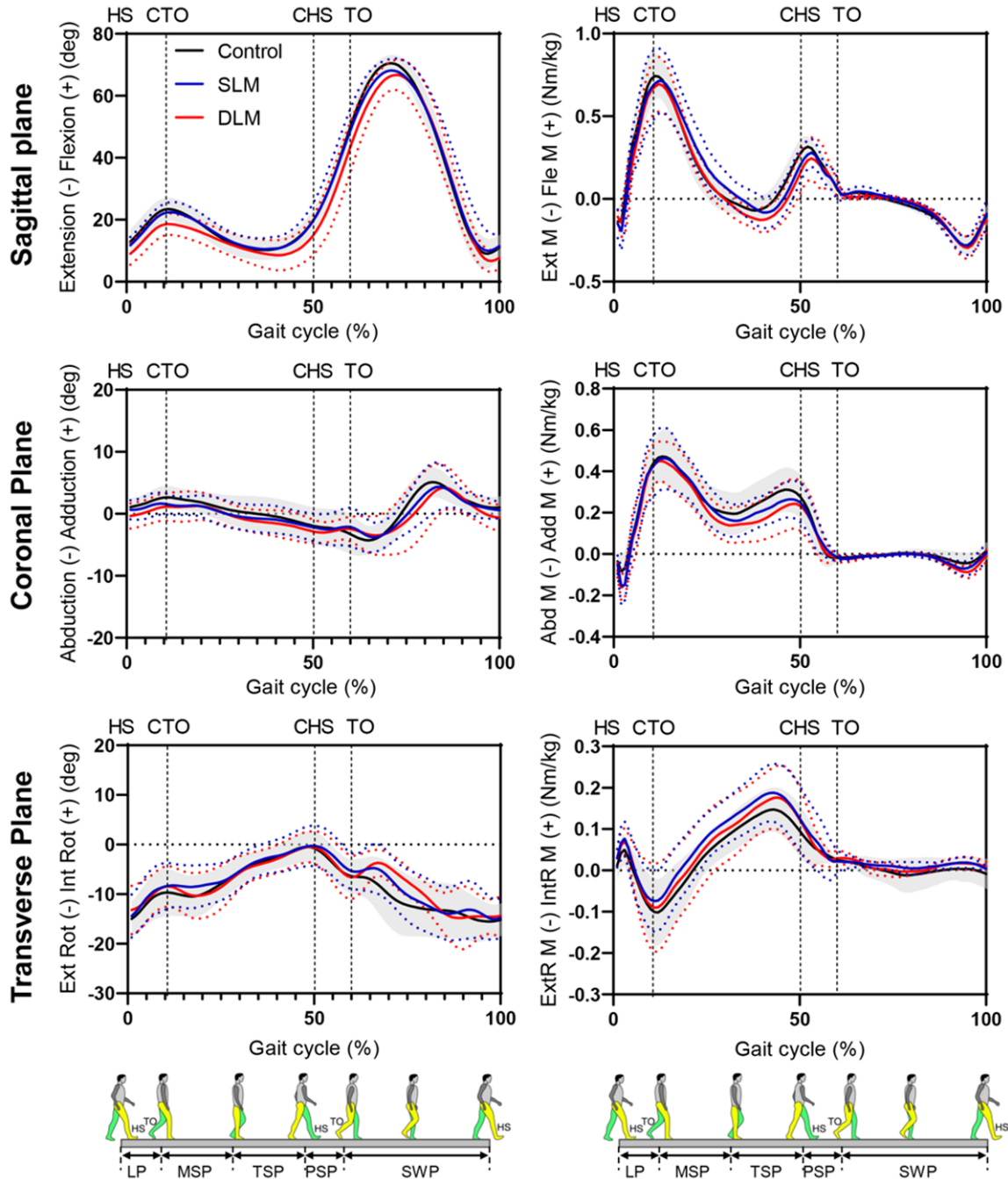


Figure 4. Post-operative knee kinematics and kinetics of the control group, SLM group, and DLM group in sagittal plane, coronal plane, and transverse plane. The gray shaded area represents SD of the control group. The dotted line above and below the curves represents the SD of the SLM and DLM groups. HS: heel strike, CHS: contralateral heel strike, TO: toe off, CTO: contralateral toe off, LP: loading phase, MSP: midstance phase, TSP: terminal stance phase, PSP: pre-swing phase, SWP: swing phase.

Kinetics

In the sagittal plane, a significantly lower first peak knee flexion moment (KFM) was observed in the SLM and DLM groups before surgery

than in the control group ($P = 0.029$, SLM and $P < 0.001$, DLM). In addition, a significant difference in first peak KFM was observed between the SLM and DLM groups ($P = 0.038$). The first peak KFM was significantly improved

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Table 2. Comparison of spatiotemporal and kinematic parameters of the control, SLM and DLM groups

Variable	Control	Pre-surgery		Post-surgery	
		SLM	DLM	SLM	DLM
Spatiotemporal parameters					
Walking speed (m/s)	1.28 ± 0.13	1.13 ± 0.12 ^a	1.11 ± 0.11 ^a	1.26 ± 0.12 ^c	1.25 ± 0.13 ^c
Cadence (steps/min)	113.26 ± 8.43	108.78 ± 8.51	112.02 ± 6.65	112.39 ± 8.35	115.37 ± 8.65
Stride length (m)	0.68 ± 0.04	0.62 ± 0.06 ^a	0.57 ± 0.06 ^a	0.66 ± 0.04 ^c	0.67 ± 0.05 ^c
Kinematics (°)					
Sagittal plane					
Maximum knee flexion angle during stance phase	23.59 ± 3.69	18.77 ± 5.52 ^a	14.68 ± 4.13 ^a	22.68 ± 3.16 ^c	19.84 ± 3.84 ^c
Maximum knee extension angle during stance phase	9.95 ± 3.08	8.08 ± 3.72	7.03 ± 3.35	9.88 ± 3.24	7.89 ± 4.10
Maximum knee flexion angle during swing phase	70.87 ± 2.55	65.96 ± 4.38 ^a	62.88 ± 4.54 ^a	69.10 ± 4.13 ^c	67.49 ± 4.66 ^c
Range of Flexion-Extension	63.36 ± 2.64	61.05 ± 3.03	58.85 ± 4.13 ^a	62.54 ± 4.26	61.64 ± 4.75 ^c
Coronal plane					
Maximum knee adduction angle during stance phase	3.18 ± 1.86	2.39 ± 2.04	4.08 ± 2.09	2.17 ± 1.72	1.95 ± 1.99
Maximum knee abduction angle	-5.83 ± 1.90	-4.52 ± 2.27	-2.39 ± 1.63 ^a	-4.71 ± 2.19	-4.78 ± 2.54 ^c
Maximum knee adduction angle during swing phase	5.97 ± 1.77	4.37 ± 2.80	6.86 ± 2.28	5.22 ± 2.98	5.03 ± 4.20
Range of Adduction-Abduction	11.91 ± 2.37	9.06 ± 2.09 ^a	9.40 ± 2.02 ^a	10.01 ± 2.21 ^c	9.95 ± 2.27
Transverse plane					
Maximum knee internal rotation angle	0.33 ± 2.73	-0.67 ± 2.95	-1.22 ± 3.34	1.18 ± 3.48	-0.03 ± 3.23
Range of Internal-External rotation	18.82 ± 4.25	16.76 ± 4.38	17.80 ± 4.43	18.48 ± 3.96	17.75 ± 3.76

^aIndicates significance of P < 0.05 between the SLM and DLM groups with the control group. ^bIndicates significance of P < 0.05 between the SLM and DLM groups. ^cIndicates significance of P < 0.05 before and after surgery.

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Table 3. Comparison of kinetic parameters of the control, SLM and DLM groups

Variable	Control	Pre-surgery		Post-surgery	
		SLM	DLM	SLM	DLM
Sagittal plane					
First peak extension moment (Nm/kg)	0.16 ± 0.10	0.22 ± 0.12	0.25 ± 0.12	0.22 ± 0.09	0.16 ± 0.08
First peak flexion moment (Nm/kg)	0.76 ± 0.13	0.63 ± 0.11 ^a	0.49 ± 0.12 ^{a,b}	0.74 ± 0.18 ^c	0.70 ± 0.16 ^c
Second peak extension moment (Nm/kg)	0.08 ± 0.07	0.13 ± 0.12	0.14 ± 0.11	0.10 ± 0.10	0.15 ± 0.08
Second peak flexion moment (Nm/kg)	0.33 ± 0.06	0.25 ± 0.10	0.27 ± 0.10	0.31 ± 0.08	0.27 ± 0.11
Coronal plane					
First peak adduction moment (Nm/kg)	0.49 ± 0.12	0.36 ± 0.08 ^a	0.43 ± 0.11	0.49 ± 0.13 ^c	0.47 ± 0.10
Second peak adduction moment (Nm/kg)	0.33 ± 0.11	0.23 ± 0.11	0.25 ± 0.07	0.28 ± 0.09	0.25 ± 0.12
Transverse plane					
Peak external rotation moment (Nm/kg)	0.11 ± 0.08	0.06 ± 0.05	0.04 ± 0.04	0.08 ± 0.07	0.10 ± 0.10
Peak internal rotation moment (Nm/kg)	0.15 ± 0.05	0.19 ± 0.06	0.18 ± 0.07	0.19 ± 0.07	0.19 ± 0.08

^aIndicates significance of $P < 0.05$ between the SLM and DLM groups with the control group. ^bIndicates significance of $P < 0.05$ between the SLM and DLM groups. ^cIndicates significance of $P < 0.05$ before and after surgery.

after surgery in both the SLM and DLM groups, and no significant difference was found between the three groups with regards to the kinetics in the sagittal plane. In the coronal plane, the SLM group had significantly lower first peak knee adduction moment (KAM) than the control group ($P = 0.011$). In contrast, no significant difference was observed between the DLM group and the control group ($P = 0.619$). After surgery, no significant difference was observed between the three groups in the coronal plane. The kinetics in the transverse plane showed no significant difference among the three groups pre- or post-operatively.

Discussion

Our study investigated the *in vivo* kinematics and kinetics of knees with SLM and DLM injury pre- and post-surgery during level walking. Our findings suggest that DLM injury is characterized by a greater extent of knee limitations in the sagittal plane than SLM injury preoperatively. The most important finding of our study was that knees with DLM injury presented with abnormal knee movement and loading in the coronal plane preoperatively. After APM, both the SLM and DLM groups showed improved knee function, and no difference was observed between the three groups, indicating that APM is an effective treatment for meniscal injury.

Gait analysis, a non-invasive motion capture technology, is commonly used to characterize the gait pattern in certain populations, further reflecting the status of knee function. An objec-

tive functional gait analysis can improve the evaluation of knee function and clinical outcomes after different therapeutic interventions. Compared to the self-selected walking speed of healthy individuals, patients in the SLM and DLM groups exhibited slower walking speed and shorter stride length. No significant difference in spatiotemporal parameters was observed with regards to cadence. Our results are consistent with findings by other investigators who noted a significant difference in self-selected walking speed preoperatively [21]. Previous studies have also demonstrated a decreased walking speed eight weeks post-operatively; however, our study showed that after APM, both the SLM and DLM groups showed increased walking speed; and no difference was observed between the three groups. Sturnieks et al. also found no significant difference in self-selected walking speed in 105 pain-free individuals (83% received medial APM, 18% received lateral APM, and 5% received both medial and lateral APM) between one and three months post-surgery [22]. The difference in observed walking speeds may be due to the age of patients and pain relief post-surgery.

Our results showed that both SLM and DLM knees presented less flexion during the loading and mid-stance phases. The passive flexion and extension limitation during the stance phase observed in knees with meniscal injury suggests that these knees may have developed a gait adaptation that effectively stiffens the

knee joint, possibly for protection from flexion angle variations during level walking [23]. Furthermore, the smaller angle of joints on the affected side is associated with the rigidity of joints and the inability to adapt limb movements as a result of meniscal injury [24]. In contrast to what we anticipated, although lower knee flexion was observed in the DLM injury group, there was no significant difference between the SLM and DLM groups. Notably, in the sagittal plane, the DLM injury group showed significantly smaller ROM of knee flexion-extension compared to healthy knees, but no difference was found between knees with SLM injury and healthy knees. As for the moments in the sagittal plane before surgery, the first peak KFM in knees with SLM or DLM injury was significantly lower than that in healthy individuals. Reduction in KFM is believed to be caused by the quadriceps avoidance strategy, which is a compensatory strategy that decreases joint loading and thereby joint pain before surgery [25]. Compared to knees with SLM injury, knees with DLM injury showed lower first peak KFM, which is associated with limited activity of the knee joint angle in the sagittal plane. The kinematic and kinetic findings in the sagittal plane support that knees with DLM injury are more severely limited in their movement than knees with SLM injury, although no significant difference in Lysholm scores was found in this study between the SLM and DLM groups pre-operatively. After APM, both the SLM and DLM groups showed improved knee function, indicating the efficacy of APM as a treatment for torn SLM and DLM [26].

Our results further showed that meniscal injury in the DLM group is characterized by reduced abduction movement. During gait cycle, higher knee adduction movement was observed in the DLM group than in the SLM and control groups, although there was no statistically significant difference. A previous study indicated that torn DLM contributed to the development of varus knee malalignment, which could lead to relatively increased loading on the medial compartment [27]. Furthermore, after APM, the thickness and width of the residual meniscus in knees with DLM injury decreased, which in turn, caused decreased varus deformity and development of valgus inclination [28]. Varus deformity in DLM knees may explain the different gait patterns in the coronal plane and high-

er knee adduction movement and lower abduction movement of DLM knees. In the coronal plane, KAM is predominantly determined by the product of the ground reaction force (GRF) vector and the perpendicular distance of this force from the center of the joint. KAM normally presents two peaks during the stance phase, with the magnitude of the first peak being highly associated with joint pain and disease severity [29, 30]. Our kinetic results suggested that no significant difference for first peak KAM was observed between healthy individuals and DLM patients, whereas a significantly lower first peak KAM was observed in the SLM group before surgery. We postulate that varus knee malalignment in DLM knees may increase the lever arm to the knee joint center, which would explain the first peak KAM being not significantly reduced to that of the control group. The findings of the present study indicated that there is an abnormal knee loading pattern in patients with DLM, but not in patients with SLM. Indeed, a previous study demonstrated that patients with a torn DLM exhibited greater absolute meniscal extrusion (AME) and relative percentage of extrusion (RPE) in the medial compartment of the knee joint than controls with a torn semilunar lateral meniscus [31]. Therefore, partial meniscectomy should be recommended for patients with DLM injury instead of conservative treatment, which will be conducive to the restoration of knee movement in the frontal plane and the redistribution of the medial and lateral compartment loading pattern. However, research on knee movement and loading pattern in intact DLM individuals is still lacking, and further studies in this regard are required. For patients with SLM injury, the cartilage contact areas of the tibiofemoral joint were significantly larger and the lateral shift of the centroid paths was significantly greater in the lateral compartment after APM, resulting in an increase in joint loading on the articular cartilage and initiation of cartilage damage [32]. Therefore, APM should be performed with caution, depending on the clinical symptoms and knee limitations after injury.

In the transverse plane, we found no differences in kinematics and kinetics between the three groups. Our results are consistent with those of a previous study that examined rotational kinematics in cadavers and suggested that rotational kinematics after meniscectomy

are very similar to those of the native knee [33]. Previous studies have shown that the anterior cruciate ligament (ACL), anterolateral ligament (ALL), iliotibial band, lateral meniscus, and medial meniscotibial ligament may act as important restraints to internal rotation of the knee [34-36]. However, the integrity of the ligament structure may explain the unchanged knee kinematics in the transverse plane. In addition, due to the high margin of error frequently associated with transverse plane measurements, the deviation of kinetics in the transverse plane was so large that no difference was observed between the three groups [37].

There are several limitations of the present study. First, the types of meniscal tear, such as radial tear, horizontal tear, and posterior meniscal root tear, were not considered due to the limited sample size. Second, only the kinematics and kinetics of the knee joint were evaluated. Further research should be performed to explore the kinematics and kinetics of the hip and ankle joints to better understand the effects of knees with DLM injury pre- and post-operatively on the coordination patterns of the lower limb during walking. Third, gait parameters were investigated during level walking at a self-selected speed. Further research with different walking speeds and more strenuous activities, such as running and stair climbing, should be conducted. Fourth, long-term follow up should be conducted to investigate the kinematic and kinetic changes between the SLM and DLM groups, although there was no significant difference between the two groups in short-term follow-up. Previous studies have shown that meniscectomy is associated with the onset and progression of lateral osteoarthritis [15, 26]. After APM, the difference in biomechanics between SLM and DLM may contribute to the difference in lateral compartment degeneration rates; longitudinal studies in this regard should be considered in the future. Fifth, further studies are required to establish the difference in lower limb biomechanics between uninjured DLM individuals and healthy individuals; this will contribute to decision-making regarding different therapeutic strategies, such as conservative treatment or surgical treatment after meniscal injury.

Conclusions

Patients in the SLM and DLM groups preoperatively exhibited gait patterns that were different

from that of the control group, indicating that the lower limb biomechanics differ between the three groups. More severe knee movement limitation in the sagittal plane was observed in the DLM group than in the SLM group, and the abnormal biomechanics in the frontal plane suggested that APM provided greater benefit to the DLM group. The performance of APM for DLM group is conducive to the restoration of abnormal knee kinematics and the redistribution of abnormal loading patterns in the medial and lateral compartments. Finally, although the SLM group showed improved knee function after APM, APM should be performed for SLM with caution considering the increased long-term risk of OA.

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Disclosure of conflict of interest

None.

Address correspondence to: Drs. Yiming Zeng and Dongyun Gu, Department of Orthopaedic Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200011, China. Tel: +86-139-1712-7219; E-mail: xyhz29@163.com (YMZ); Tel: +86-180-0191-2578; E-mail: Dongyunguj@163.com (DYG)

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