



Changes in total lower limb support moment in middle-aged patients undergoing arthroscopic partial meniscectomy – A longitudinal observational cohort study☆

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ABSTRACT

Background: Patients with a meniscal tear are frequently treated with arthroscopic partial meniscectomy (APM) which may alter the net extension moment across the entire lower limb – known as the total support moment (TSM).

Purpose: To investigate changes in TSM during walking in patients undergoing APM.

Methods: Three-dimensional motion analysis of walking was performed in individuals with meniscal tear prior to APM and 12 months after. Peak TSM, positive ankle (ASM), knee (KSM), and hip (HSM) moments at the time of peak TSM were calculated together with corresponding angular impulses.

Results: Patients ($n = 20$) were middle aged (45.9 ± 6.3 years) and the majority male (70%). At baseline a lower KSM (mean [95%CI]; $0.59 \text{ Nm/BM} \cdot \text{HT\%} [-1.93; 3.11]$, $P = 0.048$) and a trend towards lower peak TSM ($0.46 \text{ Nm/BM} \cdot \text{HT\%} [-1.82; 2.78]$, $P = 0.099$) were observed for the APM leg compared with the contralateral. Pre- versus post-APM change scores indicated a relative decrease in loading of the contralateral leg for peak TSM ($-0.49 \text{ Nm/BM} \cdot \text{HT\%} [-0.96; -0.01]$, $P = 0.047$) and a trend towards a relative increase in loading of the APM leg for peak KSM ($-0.41 \text{ Nm/BM} \cdot \text{HT\%} [-0.92; 0.09]$, $P = 0.105$). No differences were observed in angular impulse variables.

Conclusions: Prior to APM a strategy to unload the injured knee was manifested by reduced KSM and a tendency to a reduced peak TSM. A more equal distribution of joint moments between injured and contralateral legs was observed 12 months following APM.

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1. Introduction

Patients with a meniscal tear and knee symptoms are frequently treated with arthroscopic partial meniscectomy (APM) [1], and have a high risk of knee osteoarthritis (OA) [2,3]. In several symptomatic populations with knee pain or injury, differences in joint loading patterns have been observed that indicate unloading strategies of the painful joint [4,5].

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We recently reported a relative increase in frontal plane knee loading (external knee adduction moment (KAM)), in the leg undergoing APM compared with the contra-lateral leg from before surgery to 12 months after [6]. This increase in frontal plane knee joint loading may contribute to the high risk of knee OA in patients undergoing APM [7], but does not reveal the underlying redistribution of joint loads that are used to accommodate this change.

Sagittal plane joint moments induced by hip and knee extensors as well as ankle plantar flexors together constitute the lower extremity kinetic chain that overcome the effects of gravitational forces during locomotion. The net effect can be quantified with the total lower limb support moment (TSM) [7,8] which can be decomposed into the relative contribution of each joint to the TSM [8]. A motor strategy that shifts a proportion of the TSM away from the knee to the hip has been shown to reduce the peak knee extension moment, but does not equate to reduced tibiofemoral joint contact forces during running in individuals post APM [9]. While it appears that post-APM individuals place less relative load through their affected leg during running it is unknown whether this occurs during walking, a more commonly performed activity of daily living, and indeed if this represents a change from pre-surgical mechanics. A descriptive knowledge of the redistribution of joint loads in the essential task of walking in individuals with meniscal tear pre- and post APM, may offer a deeper understanding of knee loading strategies as a potential protective mechanism to limit excessive knee loads in the injured leg and thus, inform targeted rehabilitation pre- and post-APM.

The aim of this longitudinal observational sequel analysis from a cohort study was to test the hypothesis that a) individuals prior to APM demonstrate reduced TSM and knee support moment (KSM) in addition with a relatively higher distribution of ankle (ASM) and hip support moments (HSM) as a potential strategy to unload the injured knee and b) following surgery no unloading strategy of the injured knee/leg will be observed by means of TSM variables.

2. Material and methods

2.1. Design and reporting

This longitudinal observational cohort study reports ancillary data on previous published studies on changes in knee joint biomechanics and muscle strength following APM [6,10,11]. The study was reported following the “Strengthening the Reporting of Observational Studies in Epidemiology” (STROBE) Statement as a guideline.

2.2. Patients

Detailed information about patient recruitment, inclusion/exclusion criteria are reported elsewhere [6] and a flow-chart is provided in Figure 1. In brief, individuals with a medial degenerative meniscal tear eligible for APM were recruited from two public hospitals (Odense University Hospital, Odense, Lillebaelt Hospital, Kolding) and one private clinic (in Odense, Denmark) from April 2012 to September 2013. Patients were considered to have a degenerative meniscal tear based on a combination of age (35–55 years) and symptom onset. Patients replied to the following question regarding symptom onset: “How did the knee pain/problems for which you are now having surgery develop?”, with response options of: a) the pain/problem evolved slowly over time; b) as a result of a specific non-violent incident (i.e., kneeling, sliding and/or twisting or similar); and c) as a result of a violent incident (i.e., during sports, a crash or similar). Patients responding either a) or b) were considered to have a degenerative meniscal tear and were eligible [6]. Exclusion criteria were: previous knee surgery, injuries/problems limiting physical activity within the last 30 days, very low activity level (e.g. indoor walking only), and radiographic osteoarthritis defined as Kellgren–Lawrence grade 2 or above [6,12]. Ethical approval was provided by the Regional Scientific Ethics Committee of Southern Denmark (ID: S-20120006). All patients provided written informed consent.

At baseline (approximately two weeks prior to APM) age, gender, height, weight and the leg to undergo APM were noted. Furthermore, patient reported symptoms, pain, function, and quality of life were assessed using the Knee Injury and Osteoarthritis Outcome Score questionnaire (KOOS) [13]. A normalized score was calculated for each subscale (0 indicating extreme symptoms and 100 indicating no symptoms). The KOOS score has been validated in meniscectomy patients and has shown high test–retest reproducibility [13].

2.3. Gait analysis

Three-dimensional gait analyses were performed at baseline and at follow-up (12 months after APM) with patients walking barefoot at a self-selected speed. As walking speed is known to affect joint moments [14] the gait speed at the follow-up was matched with the self-selected speed at baseline (i.e. if patients walked more than 5% faster or slower at follow-up additional trials matching the baseline speed were conducted). A six-camera, 3D motion analysis system (100 Hz; Nexus version 1.8.5, Vicon, Oxford, UK) in synchrony with two force plates (1000 Hz; AMTI, OR6–7 Series Inc., Watertown, MA, US) were used to assess kinematics and kinetics, respectively.

Trajectory data were filtered using a Woltring filter (mean square error of 15 mm²), and ground reaction forces were filtered by means of a 40 Hz low-pass fourth order zero-lag Butterworth filter. The standard plug-in-gait marker set was used and external lower limb joint moments were calculated using inverse dynamics and normalized to body mass and height. The support moment of the lower limbs was analyzed at a discrete point (peak support moments) and then across the entire stance period (angular impulse support moments) [8]. The following specific variables of interest were calculated: total lower limb peak support moment (TSM), ankle joint support moment (ASM), knee joint support moment (KSM), and hip joint support moment (HSM). TSM was calculated as the first peak total support moment (0–50% of stance phase) with the corresponding moments for

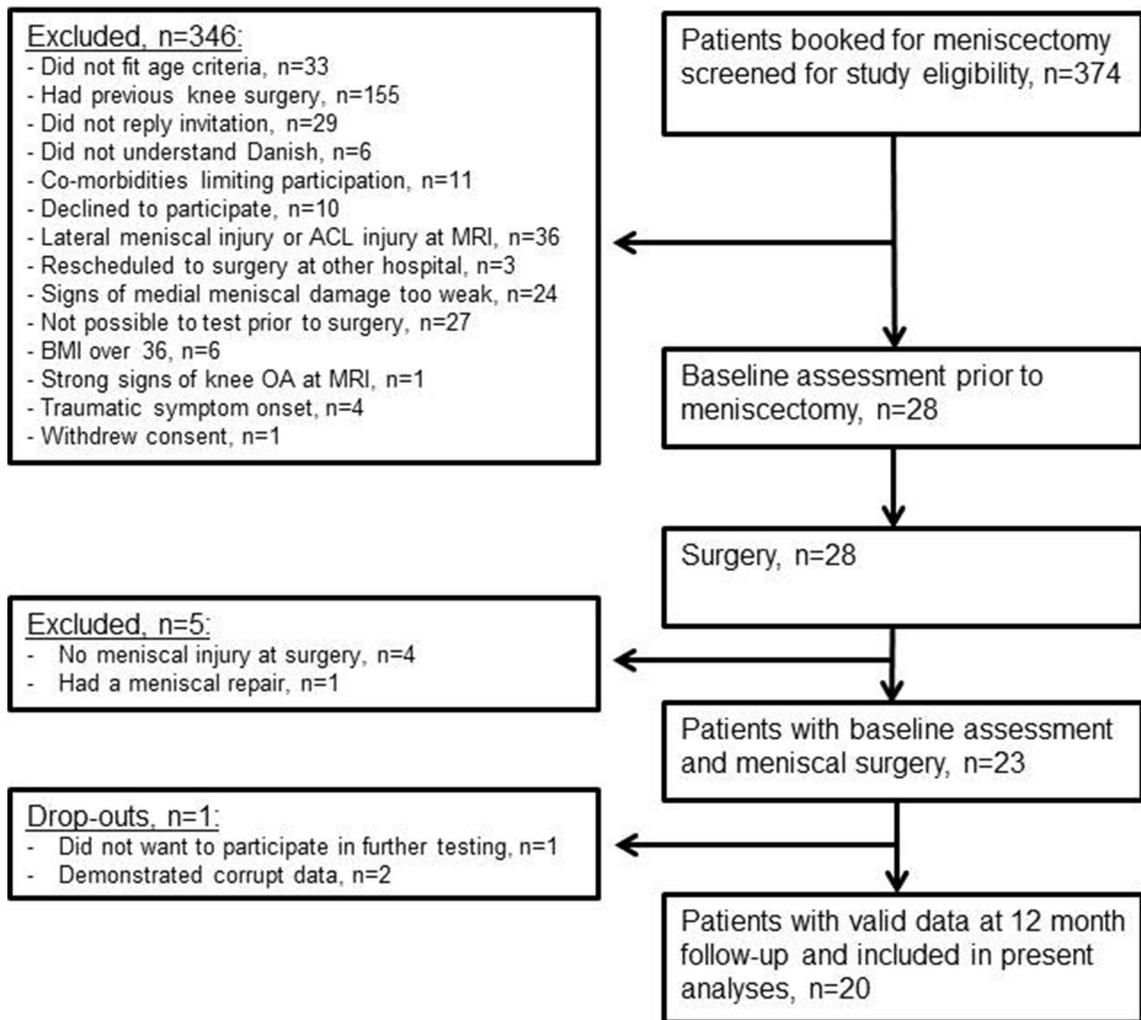


Figure 1. Patient flow in the study.

ankle, knee and hip calculated at the same time-point. In addition the total lower limb support angular impulse (ITSM), which is defined as the positive area under the total support moment-time curve, and the corresponding positive angular impulse variables for the ankle (IASM), knee (IKSM), and hip (IHSM) were calculated.

All variables were calculated for individual trials and averaged over five trials. Test-retest reliability of total joint support moment variables in healthy individuals in our laboratory is between 0.74–0.79 ($ICC_{3,5}$).

2.4. Statistics

This is a longitudinal observational sequel analysis from a cohort study based on a dataset powered for a different question [6]. Outcome variables were checked for normality using the Shapiro–Wilk test and by inspections of histograms. Data are presented as mean \pm SD with 95% confidence intervals (CIs) presented for all calculated differences. At both baseline and follow-up differences between the APM and contralateral leg were compared using a paired t-test. Changes from baseline to follow up for all measured outcomes were calculated for both the APM leg and contralateral leg and the differences in these changes between the two legs compared using a paired t-test. Statistical analyses were conducted in Stata 13 (StataCorp, College Station, TX, USA) and a P-value ≤ 0.05 was considered statistically significant and P-value $> 0.05 \leq 0.15$ was considered as a trend towards statistical significance [15].

3. Results

Three hundred and seventy four patients booked for meniscectomy were screened for eligibility and of those 346 were excluded mainly due to previous knee injury ($n = 155$), lateral meniscal injury or ACL injury at MRI ($n = 36$), not within age

criteria ($n = 33$), and not replying invitation ($n = 29$). Twenty three patients were assessed at baseline. One patient did not attend the follow-up assessment and two patients had incomplete data that could not be analyzed and consequently, 20 patients were included in the present analyses (Figure 1). Patients ($n = 20$) were middle aged (age: 45.6 ± 6.5 years), slightly overweight (BMI: 25.9 ± 3.6 kg/m²) and the majority male (70%) (Table 1).

At baseline a lower KSM (mean [95%CI]; 0.59 Nm/BM · HT% [-1.93 ; 3.11], $P = 0.048$) and a trend towards lower peak TSM (0.46 Nm/BM · HT% [-1.82 ; 2.78], $P = 0.099$) were observed for the APM leg compared with the contralateral (Table 1, Figure 2A). At follow-up no between-leg differences in support moment were observed (Table 2, Figure 2A).

The analysis on differences in change-score (baseline versus follow-up between APM and contralateral legs) indicated a relative decrease in loading of the contralateral leg for peak TSM (mean [95%CI]; -0.49 Nm/BM · HT% [-0.96 ; -0.01], $P = 0.047$) and a trend towards a relative increase in loading of the APM leg in KSM (-0.41 Nm/BM · HT% [-0.92 ; 0.09], $P = 0.105$) (Table 3).

There were no statistically significant differences at baseline, at follow-up, or for change-scores for total support impulse moment variables (Tables 1–3, Figure 2B).

4. Discussion

4.1. Summary

At baseline we observed that patients demonstrated a potential strategy to unload the injured knee evidenced by a reduced peak KSM and a tendency for a reduced peak TSM. At follow-up, a more equal distribution of support moment variables between the APM and contralateral leg were observed. It cannot be concluded from the present study whether these changes in TSM strategy are caused by the APM procedure per se, change in pain, time since APM, or other factors. Furthermore, it is not known if the observed changes in joint loads are indicative of a sustainable loading environment for longer-term knee joint health, or if these changes in joint loading play a causative role in knee OA development in APM patients.

4.2. Support moment

The use of the support moment in gait analysis provides us with information about how the individual joints are coordinated to maintain support of the body during walking [7]. Comparison of the individual joint contributions to the total support moment provides an indication of the control strategies that may be used to coordinate ambulation and the support of body weight before and after APM. In the present study we observed ~30% higher peak KSM and a trend towards a ~9% higher peak TSM at baseline for the contralateral compared with the APM leg. These differences were not detected at follow-up, demonstrating a higher distribution of load on the APM leg. Thus, further studies on the long term effect of APM on knee and total joint support moments

Table 1
Baseline patient characteristics.

Number of patients (men/women)	20 (14/6)			
Age (years)	45.6 (6.5)			
BMI (kg/m ²)	25.9 (3.6)			
Medial APM leg (right/left)	11/9			
KOOS pain	62.3 ± 18.3			
KOOS symptoms	63.8 ± 21.8			
KOOS ADL	74.3 ± 18.0			
KOOS sport/rec	36.9 ± 26.6			
KOOS QOL	44.9 ± 12.4			
Gait speed, (ms ⁻¹)	1.26 ± 0.14			
	APM leg (mean ± SD)	Contra-lateral leg (mean ± SD)	Between-leg diff (mean diff [95% CI])	P-value
Peak TSM (Nm/BM · HT%)	5.03 ± 1.94	5.49 ± 2.01	0.46 [-1.82 ; 2.78]	0.099 ^b
Peak ASM (Nm/BM · HT%)	1.28 ± 1.01	1.09 ± 0.94	-0.18 [-1.85 ; 1.49]	0.336
Peak KSM (Nm/BM · HT%)	1.98 ± 1.33	2.58 ± 1.00	0.59 [-1.93 ; 3.11]	0.048^a
Peak HSM (Nm/BM · HT%)	1.74 ± 1.55	1.80 ± 1.30	0.07 [-1.99 ; 2.14]	0.718
ITSM (Nm · s/BM · HT%)	3.32 ± 0.37	3.34 ± 0.47	0.02 [-0.59 ; 0.65]	0.698
IASM (Nm · s/BM · HT%)	2.50 ± 0.42	2.52 ± 0.31	0.01 [-0.53 ; 0.55]	0.873
IKSM (Nm · s/BM · HT%)	0.38 ± 0.20	0.44 ± 0.27	0.06 [-0.31 ; 0.43]	0.169
IHSM (Nm · s/BM · HT%)	0.43 ± 0.26	0.41 ± 0.25	0.02 [-0.32 ; 0.42]	0.540

Values are means ± standard deviation (SD) or between-leg mean difference and 95% confidence intervals (95%CI).

BMI = Body mass index, APM = arthroscopic partial meniscectomy, ADL = activity of daily living, Sport/Rec = Sport and recreational function, QOL = quality of life, TSM = total joint support moment, ASM = ankle joint support moment, KSM = knee joint support moment, HSM = hip joint support moment, ITSM = total support angular impulse, IASM = ankle joint angular impulse, IKSM = knee joint angular impulse, and IHSM = hip joint angular impulse.

^a Denotes a statistical significant difference ($P = 0.048$) for APM-leg versus contra-lateral leg.

^b Denotes a trend towards statistical significance ($P = 0.099$) for APM-leg versus contra-lateral leg.

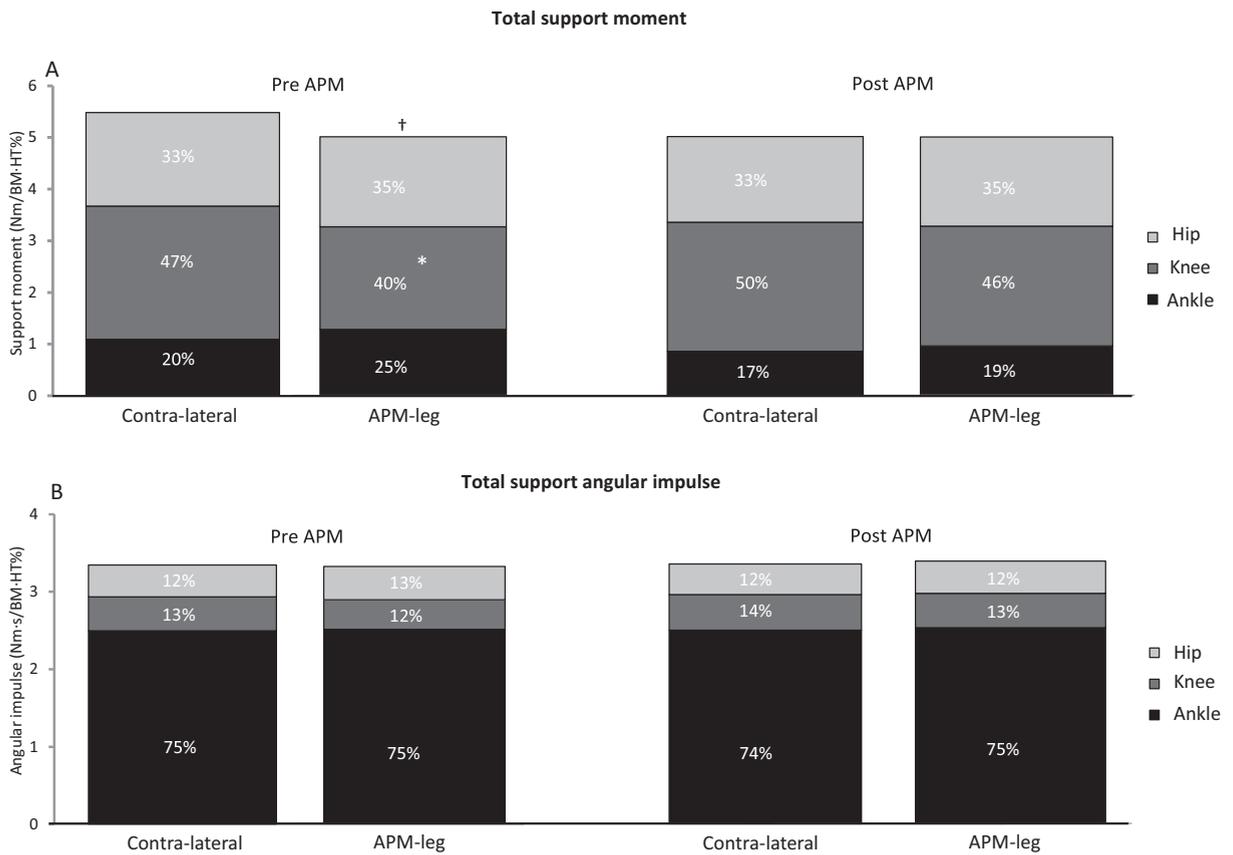


Figure 2. Total support moment variables (A) and total support angular impulse variables (B) pre and post arthroscopic partial meniscectomy (APM). *denotes a statistically significant difference ($P = 0.048$) for knee support moment pre APM. †denotes a trend towards statistical significance ($P = 0.099$) for peak total support moment pre APM.

are to be recommended to explain whether the observed alterations in intersegmental coordination and redistribution of joint loading is considered as a healthy indicator, or an OA advancing finding.

4.3. Compensatory strategy

Understanding which joints provide support during movement may provide a basis for interventions that promote successful compensatory strategies in persons with knee joint pathology [7]. Patients with knee pathology may adopt different patterns of movement that distribute the contribution to support away from painful joints [4,7]. Zeni et al. [7] demonstrated that subjects with knee OA adopted a motor control strategy during walking involving reduced KSM and increased ASM resulting in a comparable TSM with healthy

Table 2
Joint support moments, absolute values and between-leg difference at 12 months after medial APM.

	12 month outcomes			P-value
	APM leg (mean ± SD)	Contra-lateral leg (mean ± SD)	Between-leg diff. (mean diff [95% CI])	
Peak TSM (Nm/BM · HT%)	4.99 ± 2.12	5.00 ± 2.03	0.01 [−1.57; 1.59]	0.958
Peak ASM (Nm/BM · HT%)	0.95 ± 0.74	0.86 ± 0.58	−0.10 [−1.48; 1.28]	0.532
Peak KSM (Nm/BM · HT%)	2.32 ± 1.05	2.50 ± 1.21	0.18 [−1.89; 2.25]	0.445
Peak HSM (Nm/BM · HT%)	1.72 ± 1.56	1.66 ± 1.32	−0.07 [−1.57; 1.44]	0.695
ITSM (Nm · s/BM · HT%)	3.38 ± 0.44	3.35 ± 0.38	−0.03 [−0.58; 0.52]	0.609
IASM (Nm · s/BM · HT%)	2.52 ± 0.31	2.50 ± 0.34	−0.03 [−0.52; 0.47]	0.652
IKSM (Nm · s/BM · HT%)	0.44 ± 0.27	0.46 ± 0.20	0.02 [−0.48; 0.51]	0.776
IHSM (Nm · s/BM · HT%)	0.41 ± 0.25	0.39 ± 0.20	−0.02 [−0.30; 0.26]	0.485

Values are means ± standard deviation (SD) or between-leg mean difference and 95% confidence intervals (95%CI). APM = arthroscopic partial meniscectomy, TSM = total joint support moment, ASM = ankle joint support moment, KSM = knee joint support moment, HSM = hip joint support moment, ITSM = total support angular impulse, IASM = ankle joint angular impulse, IKSM = knee joint angular impulse, and IHSM = hip joint angular impulse.

Table 3

Joint support moments, change from baseline and between-leg difference on change-score after medial APM.

	Change from baseline			P-value
	APM leg (mean change [95% CI])	Contra-lateral leg (mean change [95% CI])	Between-leg diff. (mean diff [95% CI])	
Peak TSM (Nm/BM · HT%)	0.02 [−0.29; 0.34]	−0.47 [−0.97; 0.04]	−0.49 [−0.96; −0.01]	0.047^a
Peak ASM (Nm/BM · HT%)	−0.32 [−0.70; 0.06]	−0.24 [−0.56; 0.08]	0.09 [−0.27; 0.44]	0.617
Peak KSM (Nm/BM · HT%)	0.33 [−0.09; 0.75]	−0.08 [−0.56; 0.39]	−0.41 [−0.92; 0.09]	0.105 ^b
Peak HSM (Nm/BM · HT%)	−0.02 [−0.38; 0.34]	−0.15 [−0.54; 0.24]	−0.13 [−0.58; 0.31]	0.536
ITSM (Nm · s/BM · HT%)	0.06 [−0.53; 0.65]	0.01 [−0.55; 0.56]	−0.05 [−0.46; 0.35]	0.225
IASM (Nm · s/BM · HT%)	0.02 [−0.59; 0.62]	−0.01 [−0.60; 0.58]	−0.03 [−0.51; 0.46]	0.652
IKSM (Nm · s/BM · HT%)	0.06 [−0.38; 0.50]	0.08 [−0.36; 0.52]	0.02 [−0.47; 0.50]	0.776
IHSM (Nm · s/BM · HT%)	−0.01 [−0.30; 0.27]	−0.04 [−0.40; 0.33]	−0.02 [−0.30; 0.25]	0.485

Values are within-leg mean change and 95% confidence intervals (95%CI) or between-leg difference and 95%CI.

APM = arthroscopic partial meniscectomy, TSM = total joint support moment, ASM = ankle joint support moment, KSM = knee joint support moment, HSM = hip joint support moment, ITSM = total support angular impulse, IASM = ankle joint angular impulse, IKSM = knee joint angular impulse, and IHSM = hip joint angular impulse.

^a denotes a statistical significant ($P = 0.047$) difference on change-scores (baseline versus follow-up between APM and contra-lateral legs).

^b denotes a trend towards statistical significance on change-scores (baseline versus follow-up between APM and contra-lateral legs).

individuals. Recently, Willy et al. [9] observed that individuals post-APM ran with an altered distribution of the lower extremity support moments, resulting in a reduced knee extensor moment compared with their contralateral limb and matched controls. The observed redistribution of moments suggests a reorganization of motor control, in particular reduced contribution from the knee joint to the TSM at baseline may represent a compensatory strategy to reduce pain. It is also possible that this strategy is a consequence of persistent quadriceps weakness as knee extension muscle strength was shown to be decreased at baseline and normalized at follow-up for the present cohort [11]. The present findings of quadriceps weakness and reduced KSM at baseline that are not shown at follow-up underline the importance of regaining quadriceps muscle strength during rehabilitation. The change in loading strategy at follow-up, characterized by a between-leg difference in TSM (-0.49 Nm/BM · HT% [$-0.96; -0.01$]), surprisingly occurred as a result of decreased loading on the contralateral limb. Contrary to this, a non-statistically significant trend towards a between-leg increase in KSM at follow-up (-0.41 [$-0.92; 0.09$]) was observed primarily as a result of increased knee joint loading on the APM leg. We may speculate that the decrease in TSM of the contralateral limb occurs to improve between-legs symmetry of gait. However, no longitudinal studies on alterations in total support moment strategies from before to after APM exists in the literature to support this theory. Whether changes in loading strategy following APM should be attributed to a reduction in TSM of the contralateral limb or increase in the relative proportion of KSM of the APM leg needs further attention in studies powered for the specific purpose/outcomes.

4.4. Frontal and sagittal plane knee loading

The external knee adduction moment (KAM), calculated from gait analysis, is considered a valid and reliable estimate of medial tibiofemoral compartment loading [16,17] and has been linked to structural joint changes [18] in patients with knee OA. Following APM we have previously shown a relative increase in KAM, in the leg undergoing APM compared with the contra-lateral leg from before to 12 months after surgery [6]. This increase may be an important contributor to the high risk of knee OA development in patients undergoing APM. Sagittal plane knee joint moments, in combination with the KAM also contribute substantially to medial tibiofemoral compartment loading during walking [19,20], with the KAM and peak knee flexion moment together explaining 85% of the variation in compressive medial tibiofemoral compartment loading in ACL-reconstructed patients [19]. The present relative “off-loading” of the APM knee joint in the sagittal plane at baseline, in favor of increased load at the ankle, is somewhat in agreement with what has been observed in APM patients during running, and in knee OA patients during walking [7,9]. It is possible that this sagittal plane “off-loading” strategy partially offsets the increased medial compartment load as a result of a relative increase in the KAM. Nevertheless, the observed increase in KSM in the APM leg from before to after APM and the corresponding increase in KAM [6] and quadriceps strength [11] may have negative consequences for OA risk. However, the causality between quadriceps strength recovery [11], decreased pain following rehabilitation [6] and knee joint loading remains unanswered. Investigating strategies to maintain sagittal plane ‘off-loading’ of the knee may be beneficial for the risk of OA development. However, this is speculative and needs further investigation.

4.5. Limitations

This study has limitations. Due to the observational nature of this study we cannot conclude if the present redistribution of joint support moments that are not shown at follow-up are due to the APM procedure per se, quadriceps muscle force, pain or the natural time course of recovery for these patients. The minimal clinically relevant differences and change in lower limb total support moment variables in relation to risk of knee OA development, function and pain are not known. Thus, the clinical effect of the present findings remains unknown. Furthermore, we did not include a non-surgical control group (i.e. sham surgery or no treatment group) but compared support moment outcomes between the APM and contra-lateral leg as this require a relatively small sample-size which initially was based upon calculations on minimal clinically relevant difference in KAM as published in the main analysis of the present cohort [6]. Beside the risk of a potential underpowered design we also acknowledge the risk of multiplicity due to several comparisons on

many variables. However, no statistical correction or adjustment has been performed as the present explorative hypothesis generating study is not based upon statistical significance on one outcome measure but investigates the general trend of several variables. In addition a large proportion of screened patients were excluded, with the main reason being previous knee surgery in either knee. Together with three patients lost at follow-up this may limit the generalizability (i.e., external validity) of this study to patients with acute meniscal tears or APM patients in general. Finally, the non-significant observations at follow-up do not necessarily indicate equivalence and thus the current interpretation of a more equal distribution of joint loading towards a 'normalization' should be taken with caution. However, we believe the present study provides important explorative findings regarding the redistribution of joint loading pre and post APM that may inform appropriate rehabilitation strategies for APM patients.

5. Conclusion

In conclusion, we observed that individuals prior to APM demonstrated a strategy that may be adopted to unload the injured knee evidenced by a reduced KSM and a tendency for a reduced peak TSM. Furthermore, a more equal distribution of support moment variables between the APM and contralateral leg was observed following surgery. Whether these changes in TSM strategy are indicative of a sustainable loading environment for longer-term knee joint health, or if these changes in joint loading play a causative role in knee OA development in APM patients needs to be established. Further work that will determine the effectiveness of surgical procedures and examining changes in gait is an aspect that needs further examination.

Contributors

AHL, JBT, TB, and MWC conceived and designed the study. AHL and JBT participated in the data collection. AHL, JBT, TB, and MWC participated in the analysis and/or interpretation. AHL drafted the first version of the manuscript with feedback from JBT, TB and MWC. All authors approved the final version of the manuscript.

Conflict of interest statement

Authors have no competing interests to declare in relation to this work.

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