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The effects of a sleeve knee brace during stair negotiation in patients with symptomatic patellofemoral osteoarthritis

K. Doslikova [a,*], N.D. Reeves [a,b], C.N. Maganaris [a,c], V. Baltzopoulos [a,c], S.M.P. Verschueren [d], F.P. Luyten [e], R.K. Jones [f], D.T. Felson [g,h], M.J. Callaghan [b,g,i,j]

[a] Department of Life Sciences, Faculty of Science & Engineering, Manchester Metropolitan University, Manchester, UK
[b] Institute of Sport, Manchester Metropolitan University, Manchester, UK
[c] School of Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK
[d] Research Group for Musculoskeletal Rehabilitation, Department of Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven, Belgium
[e] Skeletal Biology & Engineering Research Center, Department of Development and Regeneration, Katholieke Universiteit Leuven, Leuven, Belgium
[f] School of Health Sciences, University of Salford, Salford, UK
[g] Centre for Musculoskeletal Research, University of Manchester, Manchester, UK
[h] School of Medicine, Boston University, Boston, MA, USA
[i] Department of Health Professions, Manchester Metropolitan University, Manchester, UK
[j] Manchester University Foundation NHS Trust, Manchester, UK

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ABSTRACT

Background: The patellofemoral joint is an important source of pain in knee osteoarthritis. Most biomechanical research in knee osteoarthritis has focused on the tibiofemoral joint during level walking. It is unknown what happens during stair negotiation in patients with patellofemoral joint osteoarthritis, a task commonly increasing pain. Conservative therapy for patellofemoral joint osteoarthritis includes the use of a sleeve knee brace. We aimed to examine the effect of a sleeve knee brace on knee biomechanics during stair negotiation in patellofemoral joint osteoarthritis patients.

Methods: 30 patellofemoral joint osteoarthritis patients (40–70 years) ascended and descended an instrumented staircase with force plates under two conditions – wearing a Lycra flexible knee support (Bioskin Patellar Tracking Q Brace) and no brace (control condition). Knee joint kinematics (VICON) and kinetics were recorded.

Findings: During stair ascent, at the knee, the brace significantly reduced the maximal flexion angle (2.7^0, $P = 0.002$), maximal adduction angle (2.0^0, $P = 0.044$), total sagittal range of motion (2.0^0, $P = 0.008$), total frontal range of motion (1.7^0, $P = 0.023$) and sagittal peak extension moment (0.05 Nm/kg, $P = 0.043$) compared to control. During stair descent, at the knee, the brace significantly reduced the maximal flexion angle (1.8^0, $P = 0.039$) and total sagittal range of motion (1.5^0, $P = 0.045$) compared to control.

Interpretation: The small changes in knee joint biomechanics during stair negotiation observed in our study need to be investigated further to help explain mechanisms behind the potential benefits of a sleeve knee brace for painful patellofemoral joint osteoarthritis.

1. Introduction

Osteoarthritis (OA) is the most common cause of chronic knee pain in older adults (Peat et al., 2001). Symptomatic disease affects approximately 12.5% of the US and UK populations aged over 60 years (Lawrence et al., 2008; Peat et al., 2001), and the overall prevalence of OA is increasing (Nguyen et al., 2011). The patellofemoral joint (PFJ) is a common source of symptoms in knee OA. In patients with symptomatic knee OA, the prevalence of radiographic PFJOA is 57%, and in radiographic symptomatic knee OA patients, the prevalence of PFJOA is 43% (Hart et al., 2017). Radiographic evidence of PFJOA corresponds well with severity of PFJ symptoms (Duncan et al., 2006), and even minimal radiographic findings are associated with considerable pain, stiffness and limitation of activities of daily living (Duncan et al., 2009).

Most biomechanical research in knee OA has focused on tibiofemoral joint (TFJ), but a growing body of work is emerging for the PFJ. It is

* Corresponding author at: Publications, Adelphi Real World, Bollington, UK
E-mail address: katerina.doslikova@adelphigroup.com (K. Doslikova).

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proposed that higher loading in the patellofemoral compartment leads to symptoms and structural progression (Farrokhi et al., 2011). Conservative interventions for knee OA include knee bracing to reduce the PFJ load, alter symptomology and/or reduce disease progression (Crossley and Hinman, 2011). Two randomised clinical trials on PFJOA have shown that a knee brace reduced pain (Callaghan et al., 2015; Hunter et al., 2011), but its effects on the biomechanics of the knee joint are less well known. There is evidence from static imaging studies that a knee brace may correct PFJ malalignment (Callaghan et al., 2016), increase contact area of the PFJ in standing (Callaghan et al., 2014) and that it alters knee flexion angle during level walking (McCall et al., 2014). Stair negotiation in particular causes pain in people with PFJOA (Duncan et al., 2009; van Middelkoop et al., 2018). This activity generates higher sagittal plane knee joint moments, as well as higher knee adduction moments (KAM) than level walking (Donell and Glasgow, 2007). The effects on knee joint biomechanics while ascending and descending stairs remain unknown.

The aim of this study was to investigate the effects of a sleeve knee brace on knee joint biomechanics during stair negotiation in patients with PFJOA. We hypothesised that during stair negotiation, compared to the control condition, the brace would significantly reduce sagittal knee kinematics and kinetics, and pain.

2. Methods

The study was a cross-sectional study with a random allocation of the intervention.

2.1. Participants

Thirty participants were recruited as a follow-up sample from a parent, randomised clinical trial on the effects of a sleeve knee brace in PFJOA (Callaghan et al., 2015). Ethical approval was obtained from the Central Manchester Local Research Ethics Committee and the Manchester Metropolitan University. Written informed consent was obtained from all participants prior to the testing.

2.2. Inclusion criteria

Participants were recruited from the parent trial if they were between 40 and 70 years old, and had PFJOA confirmed on radiographs obtained within the previous two years with a Kellgren Lawrence (K-L) score of two or more in the PFJ, which was equal to or greater than the K-L score in the TFJ of the same knee. Those without radiographs had confirmation of OA on magnetic resonance imaging (MRI) scan or at arthroscopy. Participants who had equal K-L scores in PFJ and TFJ had to have predominantly PFJ symptoms such as pain reproduced with stair ascent and descent, kneeling, prolonged sitting or squatting, and had to have lateral or medial patellar facet tenderness on palpation or a positive patellar compression test. The knee pain must have been present daily for the previous three months and with at least a score of 40 mm (mm) on the Visual Analogue Scale (VAS; 0 mm = no pain, 100 mm = worst imaginable pain) for their nominated aggravating activity. All radiographs were read by an experienced consultant musculoskeletal radiologist. Clinical assessments were performed by an experienced musculoskeletal physiotherapist with expertise in knee joint assessment. A detailed description of inclusion criteria of participating patients can be found in the parent trial (Callaghan et al., 2015).

2.3. Exclusion criteria

Participants were excluded if, on examination by the physiotherapist, pain emanated predominantly from the TFJ, or were due to a meniscal or ligament injury. They were also excluded if they had a diagnosis of rheumatoid arthritis or other forms of inflammatory arthritis, or chronic pain unrelated to the knee, confirmed by a medical physician. Further exclusions were an intra-articular injection of corticosteroid or hyaluronic acid into the painful knee within the previous month, or a previous patellar fracture or patellar realignment surgery.

2.4. Experimental set-up

A seven-step staircase instrumented with four individual force plates (Kistler, 300 × 500 mm), embedded into the second, third, fourth and fifth step, respectively, was used in the study. The step dimensions represented standard stair dimensions with a going of 275 mm, a riser height of 175 mm and a width of 1050 mm, complying with building standards (Government, 2013). The handrails were at a height of 900 mm above the step and in 31° of inclination on both sides. All participants wore a full-body safety harness during the stair testing as a safety precaution, but this was arranged so that there was no interference to the natural stair gait. The belayer was trained to ensure that there was always slack maintained on the harness so as not to influence the gait or kinetics of the participant. The experimental set-up is shown in Fig. 1.

Kinetic and kinematic data were collected using the force plates and a 10-camera VICON optoelectronic motion analysis system (VICON motion systems Ltd., Oxford, UK), tracking a set of 69 retro-reflective markers using a modified 6 Degrees of freedom (6 DoF) whole body model (Fig. 2) developed by Capozzo (Cappozzo et al., 1995). This kinematic model ensured that no markers needed to be placed on the brace during the stair trials. The markers were placed on specific anatomical landmarks either directly on the skin or onto tight fitting and elasticated clothing. There were 49 individual markers, 16 markers attached on four marker clusters (with four markers per cluster) for lower extremities and four markers on an elasticated headband. To optimise consistency, the same researcher palpated bony landmarks and carried out marker placement. An elasticated band secured the four lower extremity clusters.

2.5. Protocol

A static subject calibration was recorded in the position shown in Fig. 2 for each condition (brace and control). This was performed to enable labelling of the markers, and definition of the anatomical landmarks and joint segments, for application of the kinematic model. This kinematic model was then applied to the dynamic trials. Participants were then asked to ascend and descend the stairs in a step-over-step manner at a velocity controlled by a metronome set at 90 beats per minute, since variables such as joint moments can be influenced by differences in walking speed (Astephen, 2012). This rate was selected as it has previously been shown to closely match the self-selected speed in elderly people during stair negotiation (Reeves et al., 2009). Participants practiced the metronome tempo by marching on the spot several times before the instruction to set off was given and were asked to match the tempo as closely as possible.

Participants started the ascent from the base of the staircase directly in front of the first step. At the top of the staircase, they were instructed to stop before turning around and positioning themselves at the edge of the top step in readiness for descending the stairs. During the trials, participants had no restraint of head movement and did not hold onto the handrails. Data were collected barefoot.

The two conditions were: 1) wearing a Lycra flexible knee support (Bioskin Patellar Tracking Q Brace, Ossur UK, Stockport, England), and 2) wearing no brace (control condition), which were randomly ordered using sealed opaque envelopes. Static calibration was repeated for each condition as some markers needed to be repositioned due to application or removal of the brace.

Three ascending and descending trials per condition were recorded, and stance phases were analysed for the affected leg in both conditions. We tested the leg most severely, symptomatically affected by PFJOA. In the 10 participants who had bilateral PFJOA, examination by an experienced musculoskeletal physiotherapist revealed which knee was the

Fig. 1. The experimental set-up.
The photograph is for illustration of the experimental set-up only, no participants used the handrail during the trials.

most symptomatic. From this, it was decided which knee would be treated with the brace. Participants were allowed to retain or discard the realigning strap supplied with the brace based on their preferences. Knee joint angles and moments, gait speed and stride width were recorded. To assess the change in pain between the conditions during the tasks, participants were asked to mark their level of knee pain for each condition during three trials of ascent and descent separately using the VAS.

2.6. Data analysis

Kinematic and kinetic data recorded using the VICON system were labelled in VICON Nexus (Vicon Nexus 1.8.2), and then transferred and analysed using the Visual 3D software (Visual3D Student Edition v4.96.9), where the kinematic model (6 DoF) was applied, and sagittal and frontal plane knee joint angles, internal knee joint moments, gait speed and stride width were exported. The mean of six stance phases (two stance phases per trial, three trials) was used for the analysis.

Statistical analysis was performed using the Statistica software (version 10; StatSoft, Inc., Tulsa, OK, USA). Differences between the two conditions (brace and no brace) for all parameters, for both stair ascent and descent, were quantified using a dependent Student's *t*-test. Statistical significance was set at $p < 0.05$.

3. Results

Patients' characteristics are described in Table 1.

3.1. Stair ascent

When using the brace compared to the control condition, there was a significantly reduced maximal knee flexion angle (2.7^0, $P = 0.002$), maximal knee adduction angle (2.0^0, $P = 0.044$), total sagittal knee range of motion (RoM; 2.0^0, $P = 0.008$) and total frontal knee RoM (1.7^0, $P = 0.023$) (Table 2). Also, there was a significantly reduced peak knee extension moment (0.05 Nm/kg, $P = 0.043$). No significant differences between conditions were found for stride width, gait speed and pain (Table 2).

3.2. Stair descent

There was a significantly reduced maximal knee flexion angle (1.8^0, $P = 0.039$) and total sagittal knee RoM (1.5^0, $P = 0.045$) when using the brace compared to the control condition. No significant differences between the two conditions were found for other knee joint kinetics, kinematics, stride width, gait speed and pain (Table 3).

4. Discussion

This study, as far as we know, is the first to investigate the effect of a sleeve knee brace on knee joint biomechanics in patients with PFJOA during stair ascent and descent. We found that the brace reduced maximal knee angles and peak joint moments about the knee predominantly in the sagittal and, to a lesser extent, frontal plane. We found no change to the internal knee abduction moment with the brace, which was to be expected since there is no known mechanical function of this

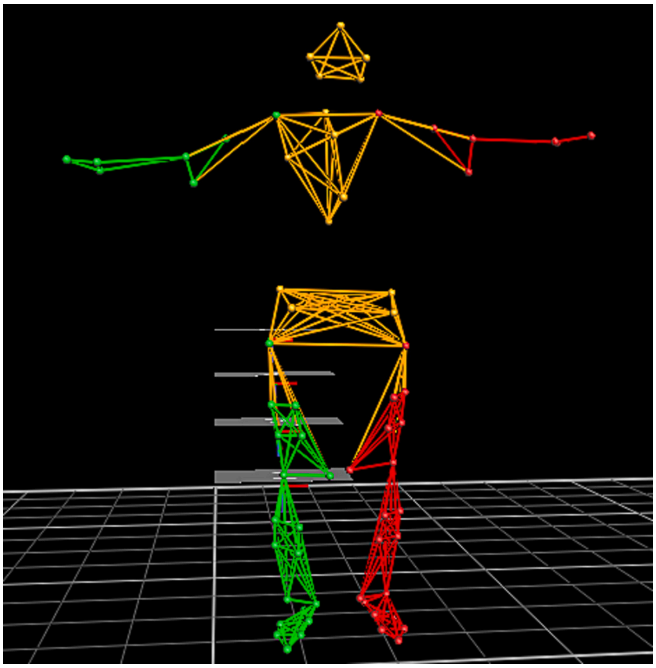

Fig. 2. The modified 6 Degrees of freedom whole body model in Vicon software with 69 retroreflective markers.
Pelvic markers: left posterior superior iliac spine, right posterior superior iliac spine, left anterior superior iliac spine, right anterior superior iliac spine, sacrum, left iliac crista, right iliac crista, left greater trochanter, right greater trochanter.
Head markers: elastic head band with four marker (left back, right back, left front, right front) and one marker for static calibration only (top head).
Trunk markers: seventh cervical vertebra, tenth thoracic vertebra, jugular notch, xiphoid process, left scapula, left acromion, right acromion.
Upper limb markers: left lateral elbow, right lateral elbow, left middle upper arm, right middle upper arm, left medial elbow, right medial elbow, left ulnar wrist, right ulnar wrist, left radial wrist, right radial wrist, left head of second metacarpal bone, right head of second metacarpal bone.
Lower limb markers: left lateral femoral epicondyle, right lateral femoral epicondyle, left medial femoral epicondyle, right medial femoral epicondyle, four left thigh markers on a cluster, four right thigh markers on a cluster, left lateral malleolus, right lateral malleolus, left medial malleolus, right medial malleolus, four left shin markers on a cluster, four right shin markers on a cluster, left heal, right heal, left head of first metatarsal bone, right head of first metatarsal bone, left head of fifth metatarsal bone, right head of fifth metatarsal bone, left base of first metatarsal bone, right base of first metatarsal bone, left base of fifth metatarsal bone, right base of fifth metatarsal bone, left tip of second toe, right tip of second toe.

Table 1
Participants' characteristics ($N = 30$).

Age, years (± SD)	57.7 (8)
Height, m (± SD)	1.66 (0.1)
Body mass, kg (± SD)	77 (16)
BMI, kg/m^2 (± SD)	27.4 (4)
Gender, % female	57

Abbreviations: BMI, Body Mass Index; kg, kilogram; m, metre; SD, standard deviation.

brace to alter the KAM.

There was no significant reduction in pain during the tasks while wearing the brace, indicating that the biomechanical changes observed were not due to an immediate reduction in pain, even though there is evidence that this brace reduced PFJOA pain when worn for a longer period (Callaghan et al., 2015). This apparent discrepancy is likely due to participants' familiarity with the brace, as they were a subgroup from

Table 2
Kinematics and kinetics during the stance phase of stair ascent for brace and control conditions.*

	Brace	Control	*P-value*
	N = 30		
MIN knee flexion angle (^{0})	12.2 (5.0)	12.9 (5.6)	*0.380*
MAX knee abduction angle (^{0})	4.0 (4.3)	3.7 (5.2)	*0.562*
MAX knee flexion angle (^{0})	73.3 (3.9)	76.0 (5.3)	*0.002*†
MAX knee adduction angle (^{0})	5.0 (5.8)	7.0 (6.9)	*0.044*†
Total RoM in the sagittal plane (^{0})	61.1 (5.7)	63.1 (6.3)	*0.008*†
Total RoM in the frontal plane (^{0})	9.0 (5.2)	10.7 (5.1)	*0.023*†
Peak knee extension moment (Nm/kg)	1.00 (0.23)	1.05 (0.23)	*0.043*†
Peak knee abduction moment (Nm/kg)	0.24 (0.16)	0.24 (0.17)	*0.947*
Stride width (m)	0.11 (0.03)	0.11 (0.02)	*0.284*
Gait speed (m/s)	0.50 (0.05)	0.50 (0.04)	*0.569*
Pain during task via VAS (mm)	25 (26)	25 (24)	*0.539*

Abbreviations: kg, kilogram; m, metre; MAX, maximal; MIN, minimal; mm, millimetre; Nm, newton-metre; RoM, range of motion; SD, standard deviation; VAS, Visual Analogue Scale
* Data are presented as mean (SD).
† Statistically significant difference between the two conditions ($p < 0.05$).

Table 3
Kinematics and kinetics during the stance phase of stair descent for brace and control conditions.*

	Brace	Control	*P-value*
	N = 30		
MIN knee flexion angle (^{0})	12.7 (3.4)	13.0 (3.3)	*0.682*
MAX knee abduction angle (^{0})	3.4 (4.2)	3.0 (4.9)	*0.509*
MAX knee flexion angle (^{0})	94.8 (5.6)	96.6 (6.1)	*0.039*†
MAX knee adduction angle (^{0})	5.6 (5.0)	5.9 (5.8)	*0.812*
Total RoM in the sagittal plane (^{0})	82.1 (5.3)	83.6 (5.6)	*0.045*†
Total RoM in the frontal plane (^{0})	9.1 (4.4)	8.9 (4.6)	*0.828*
Peak knee extension moment (Nm/kg)	0.94 (0.22)	0.96 (0.23)	*0.209*
Peak knee abduction moment (Nm/kg)	0.39 (0.24)	0.41 (0.23)	*0.145*
Stride width (m)	0.15 (0.03)	0.15 (0.02)	*0.803*
Gait speed (m/s)	0.50 (0.05)	0.49 (0.04)	*0.313*
Pain during task via VAS (mm)	29 (29)	32 (29)	*0.096*

Abbreviations: kg, kilogram; m, metre; MAX, maximal; MIN, minimal; mm, millimetre; Nm, newton-metre; RoM, range of motion; SD, standard deviation; VAS, Visual Analogue Scale
* Data are presented as mean (SD).
† Statistically significant difference between the two conditions ($p < 0.05$).

a larger, parent study. Despite this, we still observed small, yet significant biomechanical differences at the knee joint with its use.

There is some evidence from static weight bearing MRI scans that the same sleeve knee brace can induce small changes to the position of the patella relative to the femur (Callaghan et al., 2014; Callaghan et al., 2016). These small changes may increase PFJ contact area with a resulting decrease in joint stress (Powers et al., 2004). Further studies are needed to confirm this mechanism and explore its clinical significance, including its potential effect on reducing pain in the PFJ.

McWalter et al. (McWalter et al., 2011) found that the BioSkin Q brace changed patellar kinematics in people with PFJOA during a prone lying static posture in the unloaded and loaded knee using a device to simulate loading. These changes were not large enough to be clinically meaningful primarily because no reduction in pain was observed in their parent study (Hunter et al., 2011). McCall et al. (McCall et al., 2014) analysed the effects of the Bioskin Q brace on kinetics and kinematics during level walking on twelve healthy subjects. Like our study, the main effect of the brace was to reduce knee flexion during the mid stance phase of gait. Participants in the present study were allowed to retain or discard the realigning strap supplied with the brace based on their preferences. Hunter et al. (Hunter et al., 2011) found that the strap made no difference to the pain in PFJOA patients, and concluded that the brace alone without use of the strap could increase the PFJ contact area and reduce symptoms.

The only comparable study using stair negotiation in a similar patient population to our study compared three groups of subjects: Patients with PFJOA, those with mixed PFJOA/TFJOA and healthy control participants (Fok et al., 2013). The authors reported that both patient groups had reduced internal knee extension moments compared to the control group during stair ascent and stair descent, similarly to our findings between brace and control condition. No differences were found between the PFJOA or mixed OA groups, supporting our choice regarding the inclusion criteria of mixed knee OA with predominant PFJ symptoms, as both mixed knee OA and PFJOA groups behave similarly (Fok et al., 2013). Furthermore, Fok et al. (Fok et al., 2013) used a flight of three steps rather than a seven-step staircase used in our study, and the participants walked in standardised shoes and at their uncontrolled, self-selected speed, which was also different from our protocol.

The present study is novel with regard to PFJOA and stair negotiation because we investigated "true" stair negotiation as opposed to a stepping task over a single step. Furthermore, few studies have investigated the biomechanical effects of such a knee brace rather than focussing on symptomatic pain relief. However, there are some considerations. We did not examine and/or exclude participants with varus or valgus alignment, and it is known that malalignment plays an important role in joint loading measures such as the external KAM and knee OA progression, especially in TFJOA (Sharma et al., 2001; Tanamas et al., 2009). However, since we did not observe any significant changes in knee joint moments in the frontal plane when using the brace versus control condition, excluding participants with knee malalignment likely did not affect our findings and/or their interpretation. For ten participants there was no radiographic evidence of OA available, but either MRI imaging or arthroscopy confirmed the presence of PFJOA. Also, 10 participants had bilateral PFJOA, which could have affected the results. Standardised walking speed was used instead of a self-selected speed because some of the key parameters we reported on could be altered by gait speed (Astephen, 2012). This protocol ensured the task was performed under standardised conditions across all participants and both experimental conditions. Despite the fact that there were statistically significant changes in several parameters between the brace and no brace conditions, the magnitude of these changes was small. We chose not to adjust the significance levels for multiple comparisons; instead, we presented results that were significant with specific alpha levels, thus enabling the reader to draw their own conclusions with regard to the statistical confidence and scientific relevance of the reported outcomes. Also, it needs to be acknowledged that there are some potential sources of error that can be introduced during joint angle measurements, for example, marker placement inaccuracies, incorrect joint center estimation or clothing/soft tissue artifact (STA). However, we mitigated against these by: having one person place the markers on all participants; recording a static calibration for each condition (brace and control) to enable marker labelling, and definition of anatomical landmarks and joint segments, for application of the kinematic model, which was subsequently applied to the dynamic trials; and placing markers on bare skin or onto tight fitting and elasticated clothing, and having no need for markers to be placed on the brace during the movement trials. The knee joint was defined as the midpoint between lateral and medial femoral epicondyle, but the movement of the knee joint and its rotational degrees of freedom were tracked using the marker clusters attached onto the thigh and shin, reducing the problem of the movement of the STA at the knee. However, we acknowledge that there still could be a degree of movement and STA could not be disregarded, especially as the muscles continuously changed shape underneath and moved the clusters and/or the band holding them during movement (Peters et al., 2010). Lastly, the level of post-hoc statistical power ranged between 0.14 and 0.46 for the key variables of interest (maximal knee flexion angle, maximal knee adduction angle, total sagittal knee range of motion, total frontal knee range of motion and peak knee extension moment). This might be considered relatively low statistical power, reflecting smaller effect sizes. However, despite this, we were able to find significant differences in these parameters and the present sample size of 30 was similar to or larger than that of previous studies of a similar nature exploring the effects of sleeve knee brace (Callaghan et al., 2014; Callaghan et al., 2016; McCall et al., 2014; McWalter et al., 2011).

5. Conclusions

In summary, we found that a sleeve knee brace led to small, yet significant changes in knee joint angles and moments, predominantly in the sagittal and, to a lesser extent, frontal plane. These findings might be related to changes in PFJ biomechanics as found by other studies. More research is needed to explain the potential effects of sleeve knee brace on symptoms and biomechanics in patients with PFJOA.

Author contributions

All authors contributed to study conceptualisation, data capture and analysis, manuscript drafting and approve of the current manuscript for publication.

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Declaration of Competing Interest

None.

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