Mulligan Knee Taping Using Both Elastic and Rigid Tape Reduces Pain and Alters Lower Limb Biomechanics in Female Patients With Patellofemoral Pain

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Background: Evidence supports the use of Mulligan knee taping in managing patellofemoral pain (PFP). However, no studies have compared the efficacy of rigid and elastic tape using this technique.

Hypothesis: Mulligan knee taping applied with both rigid and elastic tape will produce similar reductions in knee pain, hip internal rotation, and knee flexion moments compared with no tape. Elastic tape will also be more comfortable than rigid tape.

Study Design: Controlled laboratory study.

Methods: A total of 19 female patients (mean age, 26.5 ± 4.5 years) with PFP performed a self-selected pain provocative task, single-leg squat (SLSq) task, and running task while wearing Mulligan knee taping applied with rigid tape, elastic tape at 100% tension, and no tape. Pain and taping comfort were recorded using 11-point numeric rating scales. An 18-camera motion capture system and in-ground force plates recorded 3-dimensional lower limb kinematics and kinetics for the SLSq and running tasks. Statistical analysis involved a series of repeated-measures analyses of variance. The Wilcoxon signed rank test was used for analyzing taping comfort.

Results: Compared with no tape, both rigid and elastic tape significantly reduced pain during the pain provocative task (mean difference [MD], –0.97 [95% CI, –1.57 to –0.38] and –1.42 [95% CI, –2.20 to –0.64], respectively), SLSq (MD, –1.26 [95% CI, –2.23 to –0.30] and –1.13 [95% CI, –2.09 to –0.17], respectively), and running tasks (MD, –1.24 [95% CI, –2.11 to –0.37] and –1.16 [95% CI, –1.86 to –0.46], respectively). Elastic tape was significantly more comfortable than rigid tape generally ($P = .005$) and during activity ($P = .022$). Compared with no tape, both rigid and elastic tape produced increased knee internal rotation at initial contact during the running task (MD, 5.5° [95% CI, 3.6° to 7.4°] and 5.9° [95% CI, 3.9° to 7.9°], respectively) and at the commencement of knee flexion during the SLSq task (MD, 5.8° [95% CI, 4.5° to 7.0°] and 5.8° [95% CI, 4.1° to 7.4°], respectively), greater peak knee internal rotation during the running (MD, 1.8° [95% CI, 0.4° to 3.3°] and 2.2° [95% CI, 0.9° to 3.6°], respectively) and SLSq tasks (MD, 3.2° [95% CI, 2.1° to 4.3°] and 3.8° [95% CI, 2.3° to 5.2°], respectively), and decreased knee internal rotation range of motion during the running (MD, –3.6° [95% CI, –6.1° to –1.1°] and –3.7° [95% CI, –6.2° to –1.2°], respectively) and SLSq tasks (MD, –2.5° [95% CI, –3.9° to –1.2°] and –2.0° [95% CI, –3.2° to –0.9°], respectively).

Conclusion: Mulligan knee taping with both rigid and elastic tape reduced pain across all 3 tasks and altered tibiofemoral rotation during the SLSq and running tasks.

Clinical Relevance: Both taping methods reduced pain and altered lower limb biomechanics. Elastic tape may be chosen clinically for comfort reasons.

Keywords: anterior knee pain; retropatellar pain; patellofemoral pain syndrome; biomechanics; running; single-leg squat

Patellofemoral pain (PFP) presents as pain around or behind the patella and is exacerbated by activities involving patellofemoral joint (PFJ) loading, such as ascending and descending stairs, squatting, and running.[4,12,14] It is particularly common in women, with an estimated prevalence of 12% to 13% in 18- to 35-year-old women.[7,41,44]

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Patellar malalignment and/or maltracking as a result of local, proximal, and distal factors has been implicated as a possible mechanism for altered PFJ loading in patients with PFP.[2,37,38,46] Proximally, impaired control of the hip has been demonstrated in patients presenting with PFP.[34,39,52] Excessive hip adduction and internal rotation have been proposed to increase lateral PFJ stress by effectively internally rotating the femur beneath the patella.[37,38] When combined with repetitive high-impact activities, such as running, this may increase the likelihood of developing PFP, particularly in women.[36] Evidence also supports the potential role of altered foot mechanics in PFP.[38]

Taping using rigid tape to reduce pain and alter lower limb biomechanics is supported by level 1 evidence,[2] forms part of the recommended nonoperative management of PFP,[4] and is commonly used in clinical practice in the management of PFP.[12,25,43] A variety of taping techniques have been described with varying effects.[2,8] A method described by Mulligan uses rigid adhesive tape applied in a spiral around the knee without contacting the patella.[22,32] This method has been theorized to alter patellar tracking[32] by internally rotating the tibia relative to the femur or by creating external rotation of the femur on the fixed tibia in weightbearing.[23] In asymptomatic ballet dancers, it has been shown to reduce peak hip and knee shear forces,[20] while in asymptomatic female runners, it reduced hip shear forces, as well as knee and hip sagittal plane moments.[23] Mulligan knee taping has also been shown to produce statistically significant reductions in knee pain and peak hip internal rotation and promote earlier activation of the gluteus medius compared with a no taping condition during a single-leg squat (SLSq) task in female patients with PFP.[21] The effect of Mulligan knee taping on pain and biomechanics during running and other provocative tasks in a population with PFP symptoms remains unknown; however, this is a matter of interest, as PFP is often exacerbated by running. Given that Mulligan knee taping has been proposed to alter tibial rotation,[23] it is feasible that taping may affect ankle biomechanics, but the effect of Mulligan knee taping on ankle biomechanics remains unknown. This is an area of interest, as foot biomechanics were included in a recent pathomechanical model of PFP.[38] Thus, analysis of the effect of taping on the biomechanics of the entire lower limb kinetic chain is warranted.

Both rigid and elastic tape have been used in the management of PFP.[2,8] Elastic tape has been reported to be associated with fewer skin allergies than rigid tape and to allow for stretching significantly beyond its original length.[24,45] Higher comfort levels when wearing elastic tape have been proposed to be caused by its mechanical properties.[48] Many different application methods have been described for the management of PFP using elastic tape, with tension ranging from 20% to 100% of maximal available tension[1,2,9,24,26,29,45]; however, no consensus exists as to the most appropriate amount of tension to use. When applied at 100% tension, it has been proposed to act similarly to rigid tape,[24] and while taping using the Mulligan concept is typically performed with rigid tape,[22] to date, no studies have examined the efficacy of elastic tape applied using the Mulligan knee taping technique.

Therefore, the purpose of this study was to compare the efficacy of Mulligan-applied rigid tape and Mulligan-applied elastic tape at 100% tension in adult female patients with PFP during 3 tasks: an individualized pain provocative task, an SLSq task, and a running task. Pain and taping comfort were assessed during all tasks, while lower limb biomechanics were only assessed during the SLSq and running tasks. It was hypothesized that both taping methods would result in similar reductions in knee pain compared with no tape; however, elastic tape would be more comfortable to wear. Both taping techniques were also hypothesized to reduce peak hip internal rotation angles and external knee flexion moments compared with no tape.

METHODS

Participants

Participants were recruited from community physical therapy clinics and sporting clubs and by advertising at a local university. Participants were screened by a qualified physical therapist and included if they were able to run continuously for at least 1 km and experienced anterior knee pain > 2 out of 10 on a verbal numeric rating scale (NRS) during any of the following activities: bilateral squat, SLSq, step-up, or step-down. In participants with bilateral anterior knee pain, the more symptomatic knee was chosen for the study. Participants were excluded if they had any history of skin irritability to tape, knee osteoarthritis, patellar tendinopathy, lower limb trauma, surgery or fractures or had undergone Mulligan knee taping before the study. Functional capacity was measured using the Lower Extremity Functional Scale (LEFS).[6] Ethical approval for this study was granted by the university's human research ethics committee. Informed consent was obtained from all participants, and the rights of all participants were protected.

Experimental Protocol

Participants attended the university's motion analysis laboratory on a single occasion, where 42 retroreflective markers were applied to the pelvis and lower limbs for static

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Ethical approval for this study was obtained from the Curtin University Human Research Ethics Committee (approval No. HRE2016-0053).

calibration per a modified version of The University of Western Australia static lower limb marker set protocol.[5,21] Recruitment and data collection occurred between June and December 2016. Specific markers were then removed for dynamic trials (SLSq and running tasks) per a modified version of The University of Western Australia dynamic lower limb marker set protocol.[5,21] An 18-camera, passive 3-dimensional motion analysis system (250 Hz; Vicon Nexus; Oxford Metrics) and in-ground AMTI force plates (2000 Hz; Advanced Mechanical Technology) collected kinematic and kinetic data during the SLSq and running tasks. Motion analysis and force plate data were time synchronized using Vicon Nexus software (Oxford Metrics). The Vicon motion analysis system is known to have small reconstruction errors (<2 mm)[15,28,49] and is considered a gold standard in 3-dimensional motion capture.[17,30]

After a standardized warm-up involving overground running outside the laboratory at a self-selected pace for 3 to 5 minutes, participants were familiarized with the 3 movement tasks to be performed. The SLSq task was performed on the symptomatic leg to a depth of approximately 45° of knee flexion, with the participants' arms placed across their chest and the nonweightbearing knee flexed to 90° with the hip in neutral alignment.[21] The running task was performed over a 10-m track at a standardized speed of 3.5 ± 0.5 m/s, as is common in studies involving analysis of lower limb biomechanics.[18,19] Running speed was measured by timing light gates (SpeedLight; Swift Performance Equipment). For the pain provocative task, each participant selected the activity that provoked the most pain in the symptomatic knee from the following common pain-provoking activities: SLSq, running, double-leg squat, reverse lunge, step-up, step-down, drop landing, or single-leg hop.

After familiarization, tape was applied to the symptomatic knee of each participant by physical therapists trained in the application of the Mulligan knee taping technique. The order of each taping condition, including the no taping condition, was randomized by a random number generator. Tape was applied while participants stood with the affected leg in full tibiofemoral internal rotation and 20° of knee flexion. Tape began at the neck of the fibula and was applied in a spiral fashion in an anteromedial direction inferior to the tibial tuberosity and medial knee joint line, across the popliteal fossa to the anterolateral thigh (Figure 1).[22,32] Rigid tape application involved 2 layers of 38-mm rigid tape (AMSPORTZ Rigid Sports Tape; Australian Medical Supplies), and elastic tape application involved 2 layers of elastic tape (Kinesio Tex Tape; Kinesio Holding Corporation), with each layer at 100% stretch.

For each taping condition, participants performed a single repetition of their individualized pain provocative task so as not to exacerbate their pain substantially, followed by 5 SLSq trials and by 5 running trials for each taping condition. A minimum of 2 minutes' rest between each task and 5 minutes' rest between each taping condition was provided to help skin sensation return to normal and to minimize the effects of fatigue.[2,24] After each task, participants were instructed to rate the average knee pain experienced

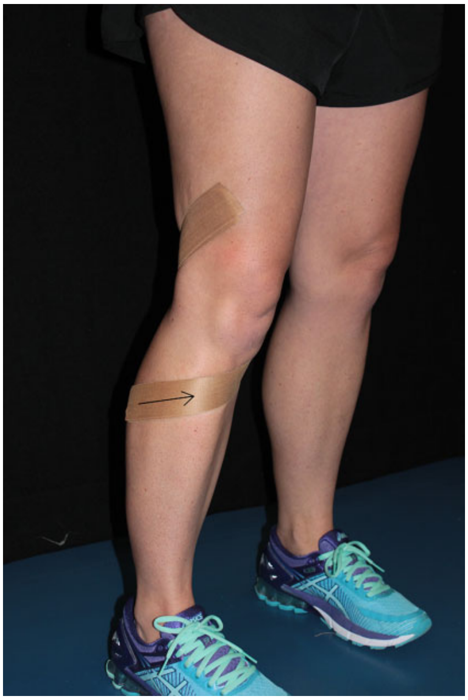

Figure 1. The Mulligan knee taping technique.

during the task using a verbal NRS (0 = no pain; 10 = maximal pain). After each taping condition, participants were instructed to rate active and general discomfort of the tape on a verbal NRS (0 = no discomfort; 10 = maximal discomfort). Active discomfort was defined as tape discomfort during the pain provocative, SLSq, and running tasks, while general discomfort was defined as tape discomfort at all other times.

Data Processing

Motion analysis data were collected and processed with Vicon Nexus software. Marker trajectories were labeled; gap-filled; and then, along with force plate data, filtered at 16 Hz using a fourth-order, zero–phase shift Butterworth digital low-pass filter. The cutoff frequency was determined using residual analysis in custom LabVIEW software (Version 2011 Service Pack 1; National Instruments). Using The University of Western Australia lower body model in Vicon Nexus software,[5] 3-dimensional peak ankle, knee, and hip joint angles and external moments were calculated throughout the stance phase for running and the eccentric phase for the SLSq, which was defined as the commencement of knee flexion (CF) to peak knee flexion. The 3-dimensional hip, knee, and ankle angles were also calculated at the time of initial contact (IC) for running and at the CF for the SLSq. In addition, range of motion (ROM) was calculated during the stance phase for running and the eccentric phase for the SLSq. Data were time normalized, and the 5 trials from each participant were averaged for analyses. Raw pain values were used for all statistical analyses. The proportion of participants achieving a 50% reduction in pain with taping was calculated.

Statistical Analysis

An a priori power calculation deemed 20 participants to be sufficient to detect a standardized group difference for an effect size of 0.6 (alpha = .05; power level = 80%) when perceived discomfort was used as the primary outcome variable.[21] Data were tested for normality using the Shapiro-Wilk test. As pain and biomechanical data were normally distributed, a series of 1-way repeated-measures analyses of variance were run to determine if any differences existed between pain scores, as well as the 3-dimensional ankle, knee, and hip joint angles and moments, across the 3 conditions (rigid, elastic, and no tape) during the running and SLSq tasks. Data were tested for sphericity using the Mauchly test of sphericity. In cases of a statistically significant analysis of variance result, pairwise comparisons with Bonferroni correction for multiple comparisons were used to check for statistically significant results between groups. Cohen (d) effect sizes were calculated for pain data, which were defined as small (0.2), medium (0.5), and large (0.8) effects.[10] As comfort data were deemed not normally distributed, the Wilcoxon signed rank test was used to compare discomfort scores between rigid and elastic tape. All statistical analyses were conducted in SPSS (Version 23; IBM), with the alpha level set at .05.

RESULTS

Participant Characteristics

A total of 21 patients were screened for participation in the study. A participant was excluded because of recent anterior cruciate ligament reconstruction. Another participant was excluded for experiencing pain levels < 2 of 10 on an NRS. Because of time and operational constraints, only 19 physically active women with PFP were able to be included in this study (mean age, 26.5 ± 4.5 years; mean height, 1.67 ± 0.06 m; mean weight, 64.7 ± 11.9 kg; mean LEFS score, 67.5 ± 8.7; mean NRS pain score, 4.2 ± 1.7 [pain provocative task], 4.2 ± 1.9 [SLSq task], 2.8 ± 1.8 [running task]). On analysis, 2 participants' biomechanical data were deemed to be unusable because of errors with markers and the motion capture system; therefore, only 17 sets of biomechanical data were included (Figure 2).

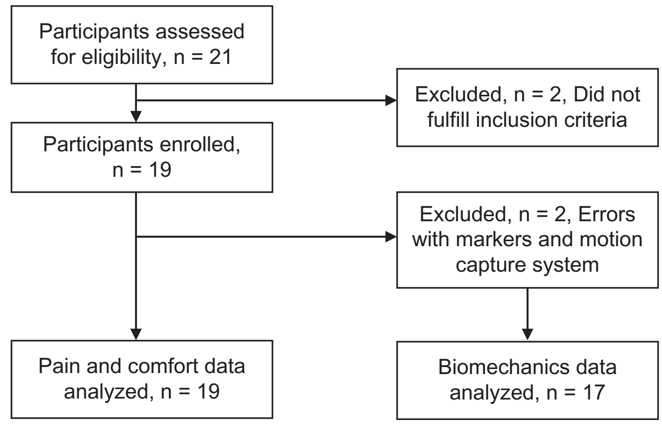

Figure 2. Flow diagram of recruitment and participation in the study.

Knee Pain

The following activities were selected as the most pain provocative to participants: SLSq (n = 7), drop landing (n = 4), reverse lunge (n = 3), step-down (n = 3), and single-leg hop (n = 2). For the pain provocative task, compared with the no tape condition, pain was significantly reduced by both Mulligan-applied rigid tape (mean difference [MD], –0.97 [SE, 0.22] [95% CI, –1.57 to –0.38]; $P = .001$; $d = 0.50$) and Mulligan-applied elastic tape (MD, –1.42 [SE, 0.30] [95% CI, –2.20 to –0.64]; $P < .001$; $d = 0.79$) (Figure 3). Pain was also significantly reduced during the running task by both rigid (MD, –1.24 [SE, 0.33] [95% CI, –2.11 to –0.37]; $P = .004$; $d = 0.77$) and elastic tape (MD, –1.16 [SE, 0.27] [95% CI, –1.86 to –0.46]; $P = .001$; $d = 0.73$) compared with the no tape condition (Figure 3). Similarly, pain was also significantly reduced during the SLSq task by both rigid (MD, −1.26 [SE, 0.37] [95% CI, –2.23 to –0.30]; $P = .008$; $d = 0.61$) and elastic tape (MD, –1.13 [SE, 0.36] [95% CI, –2.09 to −0.17]; $P = .018$; $d = 0.60$) compared with the no tape condition (Figure 3). There was no statistically significant difference in pain levels between rigid and elastic tape on any of the tasks (pain provocative: MD, 0.45 [SE, 0.39] [95% CI, −0.58 to 1.47]; $P = .791$; $d = 0.22$) (running: MD, –0.08 [SE, 0.28] [95% CI, –0.81 to 0.65]; $P > .999$; $d = 0.06$) (SLSq: MD, −0.13 [SE, 0.32] [95% CI, −0.99 to 0.72]; $P > .999$; $d = 0.06$). The number of participants achieving a 50% reduction in pain compared with no tape according to each task and taping type is seen in Table 1.

Tape Discomfort

Elastic tape (median, 2 [interquartile range (IQR), 0-4]) was significantly more comfortable to wear than rigid tape (median, 3 [IQR, 1-5]) in terms of general discomfort ($z = –2.83$; $P = .005$). Similarly, elastic tape (median, 1 [IQR, 0-3]) was significantly more comfortable to wear than rigid tape (median, 2 [IQR, 1-3]) in terms of active discomfort ($z = –2.28$; $P = .022$).

Kinematics

Running. During the stance phase for running, both taping techniques altered transverse plane motion at all lower limb joints compared with no tape. At the hip, both taping techniques significantly increased hip external rotation angles at IC and decreased external rotation ROM compared to no tape (Figure 4C and Appendix Table A1). At the knee, both taping techniques increased internal rotation angles at IC, increased peak internal rotation angles, and decreased internal rotation ROM compared with no tape (Figure 4F and Appendix Table A1). At the ankle, both taping techniques increased external rotation angles at IC compared with no tape, while only elastic tape increased peak external rotation compared with no tape (Figure 4I

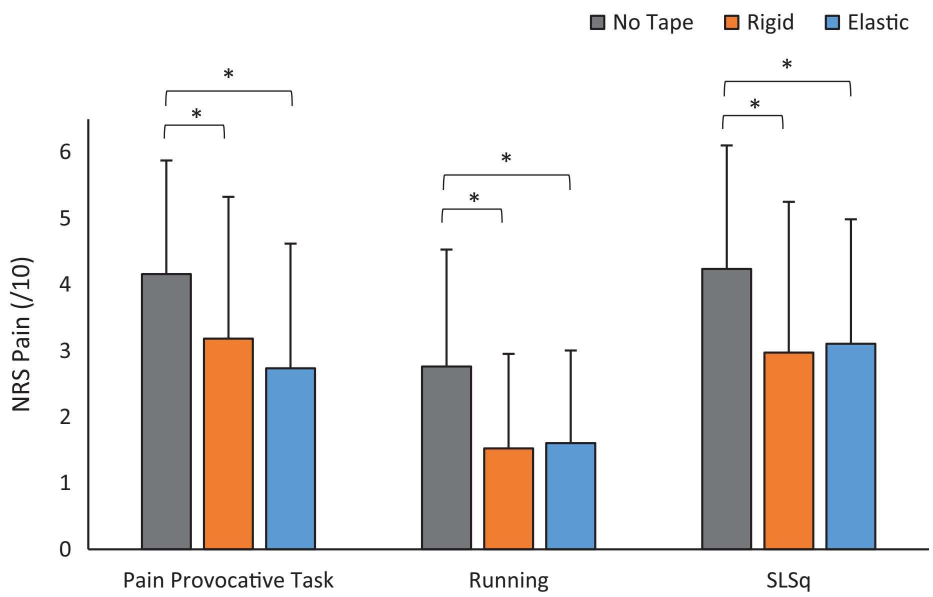

Figure 3. Mean numeric rating scale (NRS) pain scores (0 = no pain, 10 = maximal pain) during the pain provocative, running, and single-leg squat (SLSq) tasks for each taping condition: no tape, Mulligan-applied rigid tape, and Mulligan-applied elastic tape. *$P < .05$.

TABLE 1
Participants Pain Reduction According to Task and Taping Method[a]

	Pain Provocative		Running		SLSq	
	Rigid	Elastic	Rigid	Elastic	Rigid	Elastic
≥50% pain reduction	6 (32)	7 (37)	8 (42)	8 (42)	8 (42)	5 (26)
<50% pain reduction	13 (68)	12 (63)	11 (58)	11 (58)	11 (58)	14 (74)

[a]Data are presented as n (%). SLSq, single-leg squat.

and Appendix Table A1). In the frontal plane, both taping techniques reduced knee adduction angles at IC (Figure 4E and Appendix Table A1) and increased ROM at the ankle joint (Figure 4H and Appendix Table A1). Tape had no significant effect on hip, knee, and ankle sagittal plane kinematics for the running task (Figure 4).

Single-Leg Squat. During the eccentric phase for the SLSq, statistically significant changes in kinematics were noted at the knee and ankle (Figure 5). In the transverse plane, both taping techniques significantly increased knee internal rotation angles at the CF, increased peak internal rotation angles, and decreased internal rotation ROM compared with no tape (Figure 5F and Appendix Table A2). Both taping techniques also significantly increased both ankle external rotation angles at the CF and peak external rotation angles and reduced ankle external rotation ROM compared with no tape (Figure 5I and Appendix Table A2). Tape had a significant effect on hip rotation angles at the CF ($F_{2,32} = 3.789$; $P = .033$); however, no significant pairwise comparisons were evident. In the frontal plane, both taping techniques reduced knee adduction angles at the CF compared with no tape, but peak knee abduction angles were only reduced when wearing rigid tape in comparison with no tape (Figure 5E and Appendix Table A2). In the sagittal plane, at the knee joint, peak knee flexion was increased when wearing rigid tape compared with elastic tape (Figure 5D and Appendix Table A2), and knee flexion ROM was increased when wearing rigid tape compared with both no tape and elastic tape (Figure 5D and Appendix Table A2). At the ankle, rigid tape increased peak ankle dorsiflexion compared with elastic tape (Figure 5G and Appendix Table A2), and ankle ROM was increased by rigid tape compared with both no tape and elastic tape (Figure 5G and Appendix Table A2). No other significant differences were observed.

Kinetics

Running. During running, both taping techniques produced a statistically significant reduction in ankle inversion moments compared with no tape: rigid (MD, –3.0 [SE, 0.7] N·m [95% CI, –1.0 to –5.0 N·m]; $P = .003$) and elastic (MD, –4.9 [SE, 1.3] N·m [95% CI, –1.5 to –8.2 N·m]; $P = .004$) (Figure 6H). No statistically significant differences were observed in hip or knee moments (Figure 6).

Single-Leg Squat. During the SLSq, elastic tape reduced knee flexion moments compared with both rigid tape (MD,

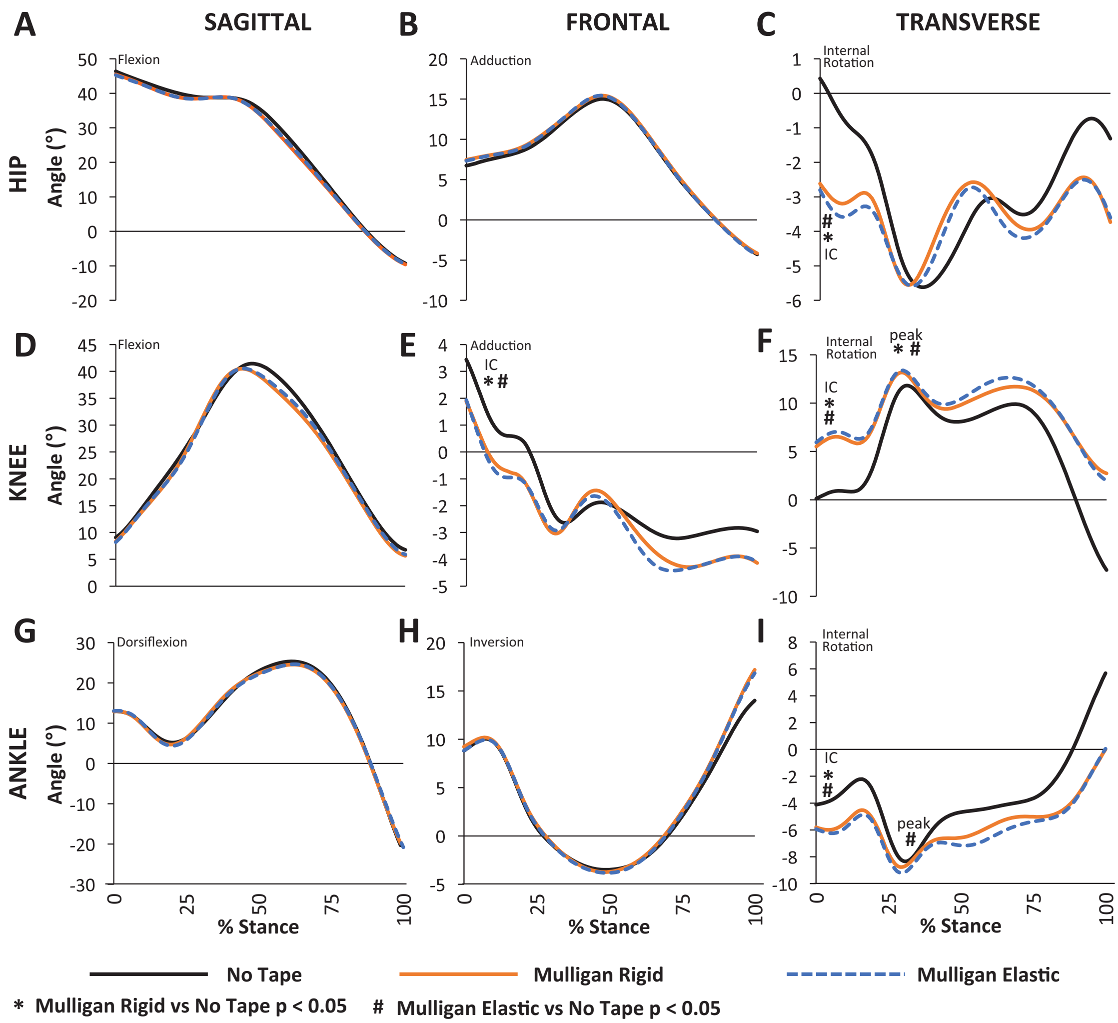

Figure 4. Three-dimensional time-normalized hip (A, B, C), knee (D, E, F), and ankle (G, H, I) joint angles (deg) during the stance phase of the running task under 3 conditions: no tape, Mulligan-applied rigid tape, and Mulligan-applied elastic tape. IC, initial contact.

–4.1 [SE, 1.0] N·m [95% CI, –1.5 to –6.7 N·m]; $P = .002$) and no tape (MD, –4.5 [SE, 1.4] N·m [95% CI, –0.7 to –8.3 N·m]; $P = .019$) (Figure 7D). In the frontal plane, knee adduction moments were increased when rigid tape was worn in comparison with no tape (MD, 4.0 [SE, 1.3] N·m [95% CI, 0.7 to 7.4 N·m]; $P = .016$) (Figure 7E). No statistically significant differences were observed in hip or ankle moments (Figure 7).

DISCUSSION

Mulligan knee taping applied with either rigid or elastic tape at 100% tension produced a statistically significant pain reduction during a self-selected pain provocative task, a moderately paced running task, and an SLSq task in female patients with PFP (Figure 3). Both types of tape produced 50% reductions in pain for 26% to 42% of participants, depending on the task being assessed (Table 1). Our study replicated the findings of Hickey et al,[21] who also found statistically significant pain reductions during an SLSq task in female patients with PFP when applying Mulligan knee taping with rigid tape. It is important to also consider whether the changes observed were clinically significant. There is no consensus in the literature regarding what constitutes a clinically significant pain reduction, with ranges from 1.5 to 2.0 cm on a 10-cm visual analog scale for pain[13] to a 41% to 48% reduction in initial pain intensity[35,47] being cited as clinically relevant. Using a percentage reduction in pain rather than an absolute pain reduction has been argued to be more relevant in cases where initial pain severity is low.[35,51] Given the generally low levels of initial pain severity in the current study, we assigned a conservative value of a 50% reduction in pain as being clinically significant. This is also consistent with the recommended goal of achieving a 50% reduction in pain when using tailored patellar taping to control patellar tilt, translation, and spin.[2] According to this

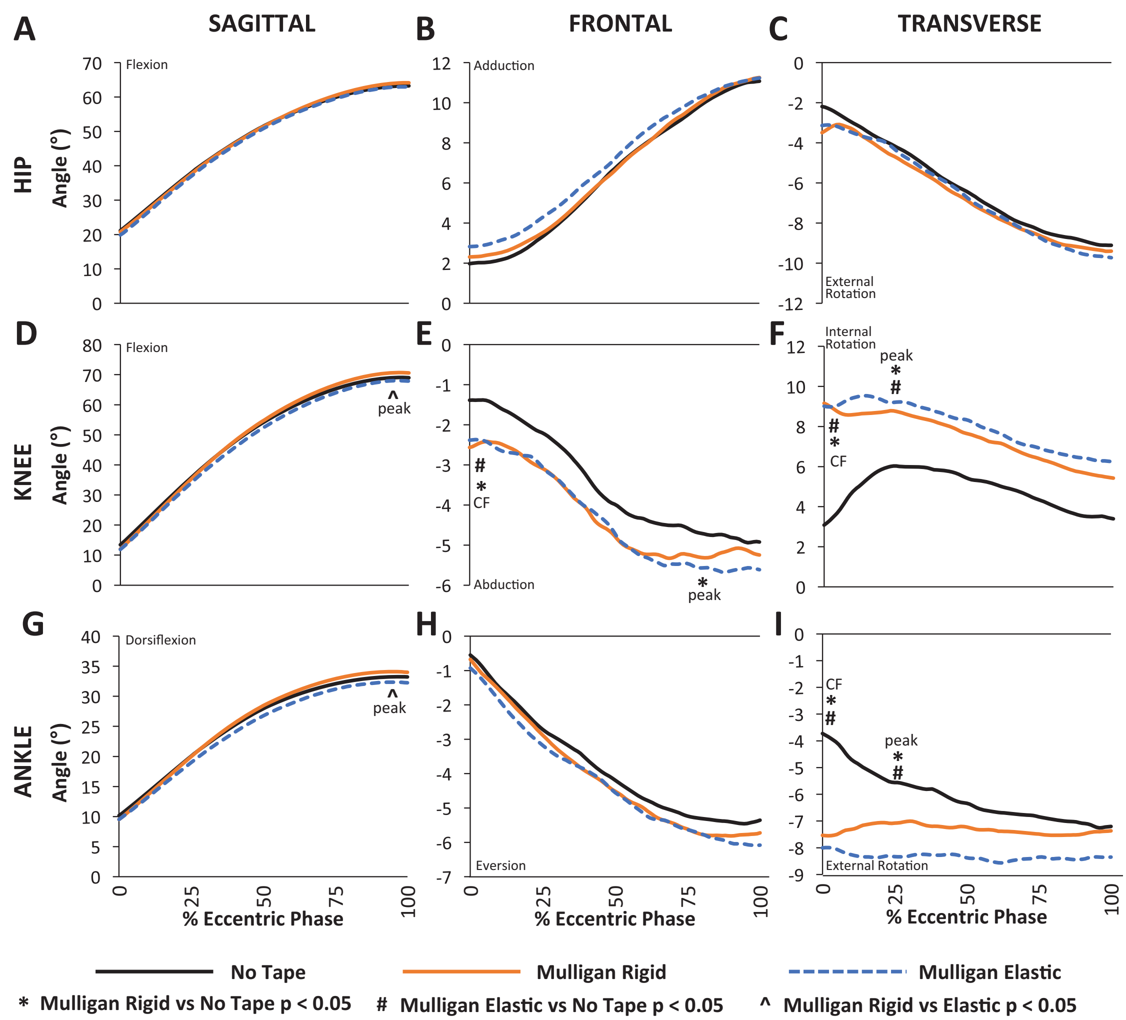

Figure 5. Three-dimensional time-normalized hip (A, B, C), knee (D, E, F), and ankle (G, H, I) joint angles (deg) during the eccentric phase (commencement of knee flexion [CF] to peak knee flexion) of the single-leg squat task under 3 conditions: no tape, Mulligan-applied rigid tape, and Mulligan-applied elastic tape.

value, Mulligan knee taping produced clinically significant pain reductions in 26% to 42% of participants, depending on the task being assessed. This highlights the need for a tailored approach when using taping to optimize the management of PFP[4,16,25,42] and is consistent with how Mulligan knee taping is used clinically, where it is only utilized if it produces a clinically significant reduction in pain.[22,32]

Consistent with our hypothesis, elastic tape was significantly more comfortable than rigid tape both in general and during activity. Given the similar effect in terms of pain reduction when using either taping type, clinicians may choose to use elastic tape when performing Mulligan knee taping because of the increased comfort when patients wear elastic tape. Future research should assess taping comfort over a longer time period, as taping of this nature is typically worn for 2 to 5 days in a clinical setting.

Mulligan knee taping has been hypothesized to reduce PFP by inducing internal tibial rotation, resulting in relative compensatory external rotation of the femur in weightbearing.[21,23] In the current study, we observed exactly this. Tibial internal rotation relative to the femur and the foot was increased during the SLSq and running tasks for both rigid and elastic tape compared with no tape. More specifically, tibial internal rotation relative to the femur was greater at IC during running and at the CF during the SLSq, and peak internal rotation angles were also increased during both tasks but not by the same magnitude, which led to a significant reduction in tibial internal rotation ROM during both tasks. This is the first study to confirm the rotational effects that Mulligan knee taping has on the tibia during dynamic tasks in a symptomatic population. Additionally, hip internal rotation was decreased at IC during running, as was hip external rotation ROM, with both rigid and elastic tape. Given that PFP has been proposed to result from increased PFJ stress related to suboptimal hip control and femoral internal rotation with respect to the tibia beneath the patella in some

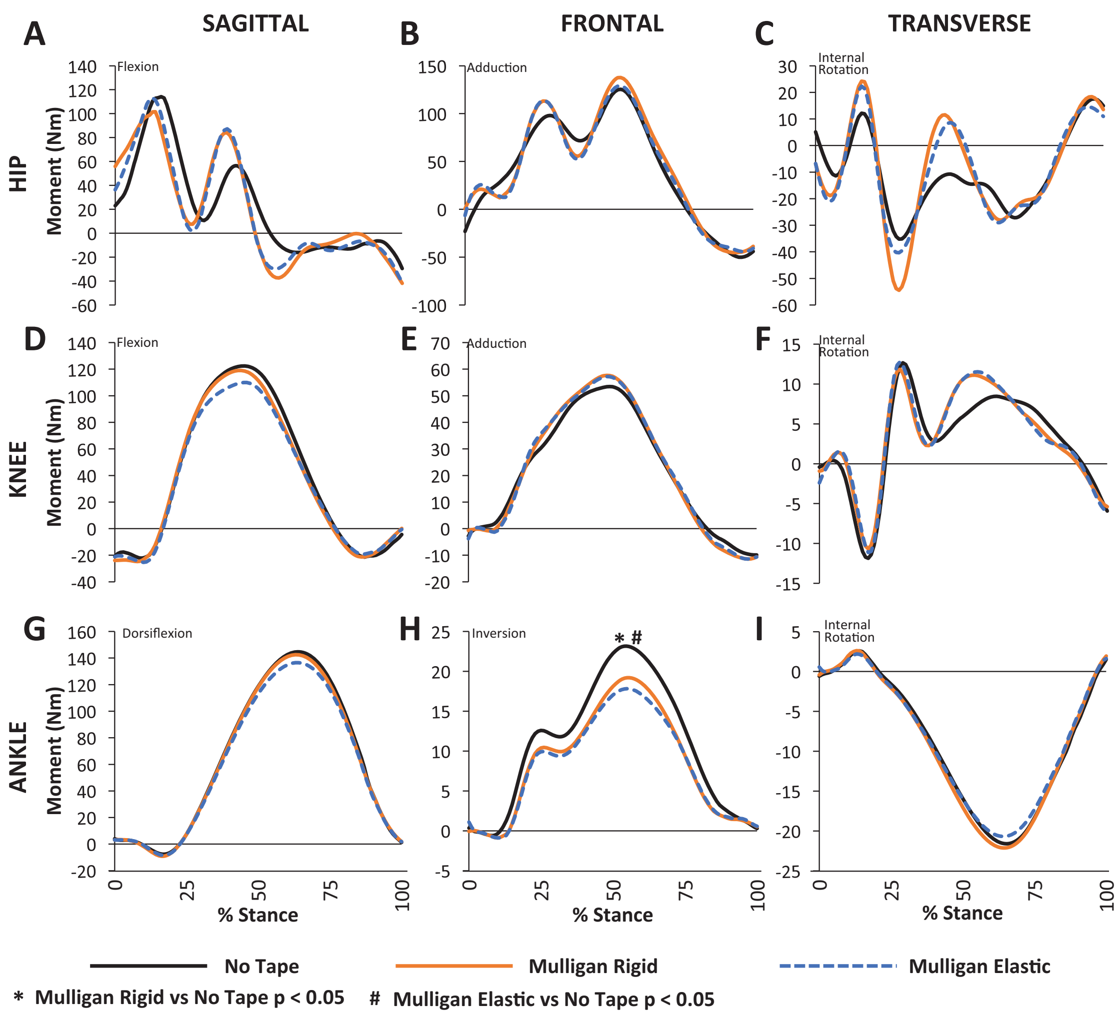

Figure 6. Three-dimensional time-normalized hip (A, B, C), knee (D, E, F), and ankle (G, H, I) external joint moments (N·m) during the stance phase of the running task under 3 conditions: no tape, Mulligan-applied rigid tape, and Mulligan-applied elastic tape.

cases,[37,38] it is possible that Mulligan knee taping indirectly alters patellar maltracking via its effect on the tibiofemoral joint. Hickey et al[21] also concluded that the reduced knee pain scores during an SLSq were likely caused by changes in peak hip internal rotation prompted by Mulligan-applied rigid tape. These biomechanical changes may explain the reduction in pain reported in the present study; however, further research to determine the cause and effect relationship is warranted.

Our hypothesis that external knee flexion moments would be reduced with Mulligan knee taping was partially supported. During the SLSq, elastic tape significantly reduced peak knee flexion moments compared with both rigid and no tape. The difference between rigid and elastic tape may be explained by the greater peak knee flexion angles and ROM observed when rigid tape was worn (Figure 5D). The reason for this increase in range is unknown; however, we speculate that it may be related to the restrictive nature of rigid tape, compelling participants to flex further to achieve the same desired angle. The difference in knee flexion moments observed between elastic and no tape during the SLSq is interesting and may be important for the management of PFP. Similarly, Mulligan-applied elastic tape reduced peak knee flexion moments compared with no tape during running (Figure 4D); however, this was no longer significant when pairwise comparisons were performed. Given that joint moments are known to be higher with running compared with walking and that PFJ loads are reported to increase in association with increased external knee flexion moments, this may be one mechanism underlying the high incidence of PFP in female runners.[40] Future research should investigate the role of elastic tape in modifying knee flexion moments in a larger sample size and with more symptom-exacerbating tasks. This may assist clinicians in selecting one taping method over another.

In the frontal plane, knee adduction angles were reduced by both taping techniques at IC during running and at the CF during the SLSq. Peak knee abduction angles were also greater when using rigid tape compared with no tape

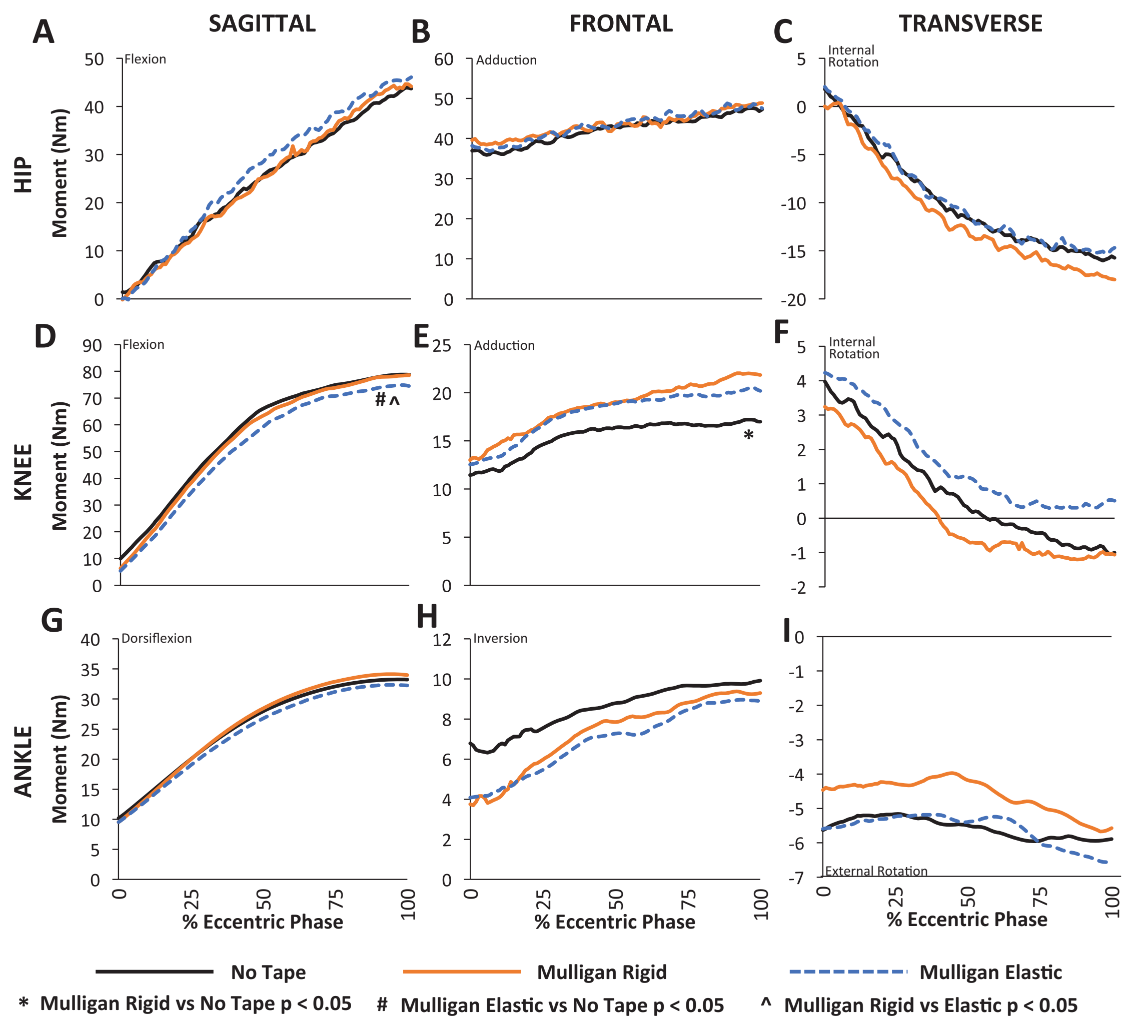

Figure 7. Three-dimensional time-normalized hip (A, B, C), knee (D, E, F), and ankle (G, H, I) external joint moments (N·m) during the eccentric phase (commencement of knee flexion to peak knee flexion) of the single-leg squat task under 3 conditions: no tape, Mulligan-applied rigid tape, and Mulligan-applied elastic tape.

during the SLSq, albeit by a small margin (MD, 0.9° [95% CI, 0.1° to 1.7°]) (Appendix Table A2). In addition, adduction moments were increased when rigid tape was worn in comparison with no tape during the SLSq. These changes, although small in magnitude, represent an alternative mechanism for the analgesic effect of Mulligan knee taping, and further research should consider the significance of these changes.

This is the first study to investigate the effects of Mulligan knee taping on the ankle joint. Both taping techniques increased ankle external rotation angles at the CF during the SLSq task, increased peak external rotation angles and reduced external rotation ROM during the SLSq task, and increased ankle external rotation angles at IC during the running task. In addition, elastic tape also reduced peak external rotation angles during running. Rigid tape increased ankle ROM into dorsiflexion when compared with no tape and elastic tape during the SLSq, which correlated with the increased knee flexion noted during the SLSq when wearing rigid tape. Additionally, we found that both rigid and elastic tape significantly reduced both total inversion-eversion ROM and peak ankle inversion moments during running compared with no tape. These changes in ankle kinematics and kinetics may represent part of the mechanism by which Mulligan knee taping reduces pain in patients with PFP, given the positive influence that foot orthoses can have on PFP pain levels[11,12] and the ability of orthoses to reduce ankle inversion moments.[27,33]

The effects of tape application were measured over a short time period within a single testing session. It is unknown whether the effects of taping on pain or biomechanics observed will be lasting or temporary or if wearing Mulligan knee taping for a more prolonged period would bring about longer term changes in pain and/or biomechanics. This is an important area for further research.

Limitations of this study need to be considered. First, the study sample only included symptomatic women with PFP with a relatively low mean body mass index and low levels of both pain and functional disability (as measured by the LEFS). Therefore, the effects of Mulligan knee taping for other population groups, such as male patients, obese patients, and patients with more severe PFP, remain unknown. Second, recent literature has suggested that patients with PFP may be subgrouped according to the factors that contribute to their presentation to tailor and optimize management and that patellar malpositioning and/or maltracking is perhaps only relevant for a subset of those with PFP.[16,38,42] The current study did not recruit according to this concept, and thus, it remains unknown whether the Mulligan knee taping technique is more effective in those with evidence of maltracking. We suggest that this is another area for future research. Third, taping was only compared with a no taping condition rather than a placebo taping condition; thus, improvements in pain may relate to a placebo effect.[31,50] Fourth, although the current study showed statistically significant changes between taping and no taping, our study may have been underpowered to determine a difference between taping types. Future research should seek to investigate the effects of longer term tape application and different elastic tape tensions, as well as the combination of taping with other elements of recommended best practice management of PFP, such as hip and knee exercises.[4]

CONCLUSION

Mulligan knee taping with either rigid or elastic tape applied at 100% tension produced statistically significant reductions in knee pain in female patients with PFP across an individualized pain provocative task, running task, and SLSq task. Clinically significant pain reductions of 50% were observed in 26% to 42% of participants, depending on the task being performed. Elastic tape was significantly more comfortable to wear than rigid tape. Both taping techniques altered biomechanics compared with no tape, particularly in the transverse plane, with statistically significant changes observed at the hip, knee, and ankle. Given the similar abilities of both taping methods to alter both pain and biomechanics, the choice of elastic or rigid tape may be left to clinician or patient preference, in line with current recommendations to individualize PFP management to each patient.[3,12,25] This research adds to the growing evidence base for the biomechanical factors contributing to PFP and the benefits of taping as part of the nonoperative management of this common condition.

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REFERENCES

1. Aytar A, Ozunlu N, Surenkok O, Baltaci G, Oztop P, Karatas M. Initial effects of Kinesio taping in patients with patellofemoral pain syndrome: a randomized, double-blind study. *Isokinet Exerc Sci*. 2011;19(2):135-142.
2. Barton C, Balachandar V, Lack S, Morrissey D. Patellar taping for patellofemoral pain: a systematic review and meta-analysis to evaluate clinical outcomes and biomechanical mechanisms. *Br J Sports Med*. 2014;48(6):417-424.
3. Barton CJ, Crossley KM. Sharing decision-making between patient and clinician: the next step in evidence-based practice for patellofemoral pain? *Br J Sports Med*. 2016;50(14):833.
4. Barton CJ, Lack S, Hemmings S, Tufail S, Morrissey D. The "Best Practice Guide to Conservative Management of Patellofemoral Pain": incorporating level 1 evidence with expert clinical reasoning. *Br J Sports Med*. 2015;49(14):923-934.
5. Besier TF, Sturnieks DL, Alderson JA, Lloyd DG. Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. *J Biomech*. 2003;36(8):1159-1168.
6. Binkley JM, Stratford PW, Lott SA, Riddle DL. The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. *Phys Ther*. 1999;79(4):371-383.
7. Callaghan MJ, Selfe J. Has the incidence or prevalence of patellofemoral pain in the general population in the United Kingdom been properly evaluated? *Phys Ther Sport*. 2007;8(1):37-43.
8. Callaghan MJ, Selfe J. Patellar taping for patellofemoral pain syndrome in adults. *Cochrane Database Syst Rev*. 2012;4:CD006717.
9. Campbell SA, Valier AR. The effect of Kinesio taping on anterior knee pain consistent with patellofemoral pain syndrome: a critically appraised topic. *J Sport Rehabil*. 2016;25(3):288-293.
10. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. New York: Lawrence Erlbaum Associates; 1988.
11. Collins N, Crossley K, Beller E, Darnell R, McPoil T, Vicenzino B. Foot orthoses and physiotherapy in the treatment of patellofemoral pain syndrome: randomised clinical trial. *Br J Sports Med*. 2009;43(3):169-171.
12. Collins NJ, Barton CJ, van Middelkoop M, et al. 2018 consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th International Patellofemoral Pain Research Retreat, Gold Coast, Australia, 2017. *Br J Sports Med*. 2018;52(18):1170-1178.
13. Crossley KM, Bennell KL, Cowan SM, Green S. Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Arch Phys Med Rehabil*. 2004;85(5):815-822.
14. Crossley KM, Stefanik JJ, Selfe J, et al. 2016 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester, part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. *Br J Sports Med*. 2016;50(14):839-843.
15. Ehara Y, Fujimoto H, Miyazaki S, Mochimaru M, Tanaka S, Yamamoto S. Comparison of the performance of 3D camera systems II. *Gait Posture*. 1997;5(3):251-255.
16. Ferrari D, Briani RV, de Oliveira Silva D, et al. Higher pain level and lower functional capacity are associated with the number of altered kinematics in women with patellofemoral pain. *Gait Posture*. 2018;60:268-272.
17. Galna B, Barry G, Jackson D, Mhiripiri D, Olivier P, Rochester L. Accuracy of the Microsoft Kinect sensor for measuring movement in people with Parkinson's disease. *Gait Posture*. 2014;39(4):1062-1068.
18. Gruber AH, Boyer KA, Derrick TR, Hamill J. Impact shock frequency components and attenuation in rearfoot and forefoot running. *J Sport Health Sci*. 2014;3(2):113-121.
19. Hamill J, Gruber AH, Derrick TR. Lower extremity joint stiffness characteristics during running with different footfall patterns. *Eur J Sport Sci*. 2014;14(2):130-136.

20. Hendry D, Campbell A, Ng L, Grisbrook TL, Hopper DM. Effect of Mulligan's and Kinesio knee taping on adolescent ballet dancers knee and hip biomechanics during landing. *Scand J Med Sci Sports*. 2015; 25(6):888-896.
21. Hickey A, Hopper D, Hall T, Wild CY. The effect of the Mulligan knee taping technique on patellofemoral pain and lower limb biomechanics. *Am J Sports Med*. 2016;44(5):1179-1185.
22. Hing W, Hall T, Mulligan B. *The Mulligan Concept of Manual Therapy: Textbook of Techniques*. 2nd ed. Chatswood, New South Wales: Elsevier Australia; 2020.
23. Howe A, Campbell A, Ng L, Hall T, Hopper D. Effects of two different knee tape procedures on lower-limb kinematics and kinetics in recreational runners. *Scand J Med Sci Sports*. 2015; 25(4):517-524.
24. Kase K, Wallis J, Kase T. *Clinical Therapeutic Applications of the Kinesio Taping Methods*. 2nd ed. Albuquerque, New Mexico: Kinesio; 2003.
25. Lack S, Neal B, De Oliveira Silva D, Barton C. How to manage patellofemoral pain: understanding the multifactorial nature and treatment options. *Phys Ther Sport*. 2018;32:155-166.
26. Lan TY, Lin WP, Jiang CC, Chiang H. Immediate effect and predictors of effectiveness of taping for patellofemoral pain syndrome: a prospective cohort study. *Am J Sports Med*. 2010;38(8):1626-1630.
27. MacLean C, Davis IM, Hamill J. Influence of a custom foot orthotic intervention on lower extremity dynamics in healthy runners. *Clin Biomech*. 2006;21(6):623-630.
28. Merriaux P, Dupuis Y, Boutteau R, Vasseur P, Savatier X. A study of Vicon system positioning performance. *Sensors (Basel)*. 2017; 17(7):1591.
29. Miller J, Westrick R, Diebal A, Marks C, Gerber J. Immediate effects of lumbopelvic manipulation and lateral gluteal Kinesio taping on unilateral patellofemoral pain syndrome: a pilot study. *Sports Health*. 2013; 5(3):214-219.
30. Mjosund HL, Boyle E, Kjaer P, Mieritz RM, Skallgard T, Kent P. Clinically acceptable agreement between the ViMove wireless motion sensor system and the Vicon motion capture system when measuring lumbar region inclination motion in the sagittal and coronal planes. *BMC Musculoskelet Disord*. 2017;18(1):124.
31. Montalvo AM, Cara EL, Myer GD. Effect of kinesiology taping on pain in individuals with musculoskeletal injuries: systematic review and meta-analysis. *Phys Sportsmed*. 2014;42(2):48-57.
32. Mulligan B. *Manual Therapy: NAGS, SNAGS, MWMS Etc*. 7th ed. Wellington, New Zealand: Plane View Services; 2018.
33. Mundermann A, Nigg BM, Humble RN, Stefanyshyn DJ. Orthotic comfort is related to kinematics, kinetics, and EMG in recreational runners. *Med Sci Sports Exerc*. 2003;35(10):1710-1719.
34. Nakagawa TH, Moriya ET, Maciel CD, Serrao FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther*. 2012;42(6): 491-501.
35. Ng GY, Cheng JM. The effects of patellar taping on pain and neuromuscular performance in subjects with patellofemoral pain syndrome. *Clin Rehabil*. 2002;16(8):821-827.
36. Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. *Med Sci Sports Exerc*. 2013;45(6):1120-1124.
37. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *J Orthop Sports Phys Ther*. 2010;40(2): 42-51.
38. Powers CM, Witvrouw E, Davis IS, Crossley KM. Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester, UK, part 3. *Br J Sports Med*. 2017;51(24):1713-1723.
39. Rathleff MS, Rathleff CR, Crossley KM, Barton CJ. Is hip strength a risk factor for patellofemoral pain? A systematic review and meta-analysis. *Br J Sports Med*. 2014;48(14):1088.
40. Roos PE, Barton N, van Deursen RW. Patellofemoral joint compression forces in backward and forward running. *J Biomech*. 2012;45(9): 1656-1660.
41. Roush JR, Bay RC. Prevalence of anterior knee pain in 18-35 year-old females. *Int J Sports Phys Ther*. 2012;7(4):396-401.
42. Selfe J, Janssen J, Callaghan M, et al. Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs). *Br J Sports Med*. 2016;50(14):873-880.
43. Smith BE, Hendrick P, Bateman M, et al. Current management strategies for patellofemoral pain: an online survey of 99 practising UK physiotherapists. *BMC Musculoskelet Disord*. 2017;18(1):181.
44. Smith BE, Selfe J, Thacker D, et al. Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. *PLoS One*. 2018;13(1):e0190892.
45. Song CY, Huang HY, Chen SC, Lin JJ, Chang AH. Effects of femoral rotational taping on pain, lower extremity kinematics, and muscle activation in female patients with patellofemoral pain. *J Sci Med Sport*. 2015;18(4):388-393.
46. Souza RB, Draper CE, Fredericson M, Powers CM. Femur rotation and patellofemoral joint kinematics: a weight-bearing magnetic resonance imaging analysis. *J Orthop Sports Phys Ther*. 2010;40(5): 277-285.
47. Tubach F, Ravaud P, Baron G, et al. Evaluation of clinically relevant changes in patient reported outcomes in knee and hip osteoarthritis: the minimal clinically important improvement. *Ann Rheum Dis*. 2005; 64(1):29-33.
48. Tunakova V, Tunak M, Mullerova J, Kolinova M, Bittner V. Material, structure, chosen mechanical and comfort properties of kinesiology tape. *J Textile Institute*. 2017;108(12):2132-2146.
49. van der Kruk E, Reijne MM. Accuracy of human motion capture systems for sport applications: state-of-the-art review. *Eur J Sport Sci*. 2018;18(6):806-819.
50. Warden SJ, Hinman RS, Watson MA Jr, Avin KG, Bialocerkowski AE, Crossley KM. Patellar taping and bracing for the treatment of chronic knee pain: a systematic review and meta-analysis. *Arthritis Rheum*. 2008;59(1):73-83.
51. Wild CY, Hickey A, Hall T. The effect of the Mulligan knee taping technique on patellofemoral pain and lower limb biomechanics: response. *Am J Sports Med*. 2016;44(8):NP39-NP40.
52. Willson JD, Kernozek TW, Arndt RL, Reznichek DA, Straker JS. Gluteal muscle activation during running in females with and without patellofemoral pain syndrome. *Clin Biomech*. 2011;26(7): 735-740.

APPENDIX

TABLE A1
Post Hoc Comparisons for Hip, Knee, and Ankle Joint Angles (deg) During Running[a]

	Rigid vs No Tape			Elastic vs No Tape			Rigid vs Elastic		
	MD (SE)	95% CI	*P* Value	MD (SE)	95% CI	*P* Value	MD (SE)	95% CI	*P* Value
Hip									
Sagittal plane									
IC	–0.9 (0.6)	–2.5 to 0.8	.534	–1.1 (0.6)	–2.7 to 0.4	.219	0.3 (0.5)	–1.1 to 1.6	>.999
Peak flexion	–0.9 (0.6)	–2.4 to 0.6	.395	–0.9 (0.6)	–2.5 to 0.7	.496	0.0 (0.4)	–1.2 to 1.1	>.999
ROM	–0.6 (0.7)	–2.5 to 1.4	>.999	–1.4 (1.1)	–4.2 to 1.5	.648	0.8 (0.9)	–1.6 to 3.2	>.999
Frontal plane									
IC	2.9 (2.1)	–2.9 to 8.6	.607	0.6 (0.4)	–0.4 to 1.6	.388	2.3 (2.2)	–3.5 to 8.1	.939
Peak adduction	0.3 (0.5)	–1.0 to 1.6	>.999	0.4 (0.4)	–0.7 to 1.5	.994	–0.1 (0.4)	–1.1 to 0.9	>.999
ROM	0.2 (0.5)	–1.3 to 1.6	>.999	0.4 (0.4)	–0.6 to 1.3	>.999	–0.2 (0.5)	–1.4 to 1.0	>.999
Transverse plane									
IC	–3.1 (0.8)	–5.2 to –0.9	.005[b]	–3.3 (0.7)	–5.3 to –1.3	.001[b]	0.2 (0.5)	–1.1 to 1.6	>.999
Peak external rotation	0.2 (0.7)	–1.6 to 1.9	>.999	–0.0 (0.6)	–1.7 to 1.6	>.999	0.2 (0.4)	–0.8 to 1.3	>.999
ROM	–3.2 (1.1)	–6.1 to –0.4	.022[b]	–3.2 (1.1)	–6.2 to –0.3	.030[b]	0.0 (0.6)	–1.7 to 1.7	>.999
Knee									
Sagittal plane									
IC	–0.7 (0.6)	–2.3 to 0.9	.749	–0.9 (0.8)	–2.9 to 1.1	.783	0.2 (0.6)	–1.4 to 1.7	>.999
Peak flexion	–0.9 (0.5)	–2.2 to 0.4	.223	–0.7 (0.5)	–2.0 to 0.6	.562	–0.3 (0.3)	–1.2 to 0.7	>.999
ROM	0.2 (0.9)	–2.2 to 2.5	>.999	0.5 (0.8)	–1.7 to 2.6	>.999	–0.3 (0.6)	–1.8 to 1.2	>.999
Frontal plane									
IC	–1.6 (0.4)	–2.6 to –0.6	.002[b]	–1.5 (0.3)	–2.4 to –0.6	.001[b]	–0.1 (0.3)	–0.8 to 0.7	>.999
Peak abduction	0.3 (0.3)	–0.5 to 1.0	>.999	0.5 (0.3)	–0.3 to 1.3	.371	–0.2 (0.2)	–0.7 to 0.2	.402
ROM	–0.7 (0.4)	–1.8 to 0.4	.330	–0.6 (0.5)	–1.8 to 0.6	.603	–0.1 (0.3)	–0.8 to 0.6	>.999
Transverse plane									
IC	5.5 (0.7)	3.6 to 7.4	<.001[b]	5.9 (0.7)	3.9 to 7.9	<.001[b]	–0.4 (0.5)	–1.9 to 1.0	>.999
Peak internal rotation	1.8 (0.5)	0.4 to 3.3	.010[b]	2.2 (0.5)	0.9 to 3.6	.001[b]	–0.4 (0.2)	–0.9 to 0.2	.215
ROM	–3.6 (0.9)	–6.1 to –1.1	.004[b]	–3.7 (0.9)	–6.2 to –1.2	.003[b]	–0.1 (0.6)	–1.4 to 1.6	>.999
Ankle									
Sagittal plane									
IC	–0.1 (0.7)	–1.9 to 1.8	>.999	0.1 (0.4)	–0.9 to 1.0	>.999	–0.1 (0.7)	–2.0 to 1.8	>.999
Peak dorsiflexion	–0.7 (0.3)	–1.5 to 0.2	.161	–0.6 (0.3)	–1.5 to 0.2	.169	0.0 (0.3)	–0.7 to 0.7	>.999
ROM	–1.5 (0.8)	–3.6 to 0.6	.209	–2.1 (0.8)	–4.2 to 0.1	.058	0.5 (0.6)	–1.1 to 2.2	>.999
Frontal plane									
IC	0.4 (0.4)	–0.7 to 1.5	.927	0.0 (0.4)	–0.9 to 1.0	>.999	0.4 (0.3)	–0.4 to 1.2	.557
Peak eversion	–0.1 (0.3)	–0.9 to 0.6	>.999	–0.3 (0.2)	–0.9 to 0.3	.726	–0.2 (0.2)	–0.4 to 0.7	>.999
ROM	–2.5 (0.6)	–0.9 to −4.1	.002[b]	–2.5 (0.6)	–0.9 to −4.1	.002[b]	0.0 (0.3)	–0.8 to 0.8	>.999
Transverse plane									
IC	1.9 (0.4)	0.9 to 2.9	<.001[b]	2.0 (0.3)	1.1 to 2.9	<.001[b]	0.1 (0.3)	–0.6 to 0.9	>.999
Peak external rotation	0.8 (0.3)	0.0 to 1.7	.059	1.2 (0.4)	0.0 to 2.3	.043[b]	0.3 (0.2)	–0.3 to 1.0	.560
ROM	–1.0 (0.4)	–2.1 to 0.0	.061	–0.8 (0.4)	–1.9 to 0.3	.184	–0.2 (0.2)	–0.8 to 0.4	.981

[a]Positive values indicate increased flexion in the sagittal plane, increased adduction/inversion in the frontal plane, and increased internal rotation in the transverse plane. IC, initial contact; MD, mean difference; ROM, range of motion.

[b]Statistically significant difference between taping conditions ($P < .05$).

TABLE A2
Post Hoc Comparisons for Hip, Knee, and Ankle Joint Angles (deg) During the Single-Leg Squat[a]

	Rigid vs No Tape			Elastic vs No Tape			Rigid vs Elastic		
	MD (SE)	95% CI	*P* Value	MD (SE)	95% CI	*P* Value	MD (SE)	95% CI	*P* Value
Hip									
Sagittal plane									
CF	–0.4 (0.8)	–2.6 to 1.8	>.999	–1.3 (1.0)	–3.9 to 1.3	.619	0.9 (0.8)	–1.3 to 3.1	.891
Peak flexion	1.0 (0.7)	–1.0 to 3.0	.635	–0.3 (0.9)	–2.6 to 2.0	>.999	1.3 (0.8)	–0.8 to 3.4	.380
ROM	1.4 (0.9)	–1.1 to 3.8	.463	1.0 (1.3)	–2.5 to 4.6	>.999	0.3 (0.9)	–2.2 to 2.9	>.999
Frontal plane									
CF	0.3 (0.5)	–0.9 to 1.6	>.999	0.8 (0.4)	–0.1 to 1.8	.088	–0.5 (0.5)	–1.8 to 0.8	.913
Peak adduction	0.3 (0.5)	–0.9 to 1.5	>.999	0.3 (0.5)	–1.0 to 1.5	>.999	0.0 (0.6)	–1.5 to 1.5	>.999
ROM	0.0 (0.5)	–1.3 to 1.3	>.999	–0.6 (0.3)	–1.4 to 0.2	.180	0.6 (0.5)	–0.6 to 1.8	.639
Transverse plane									
CF	1.0 (0.4)	–0.1 to 2.1	.068	0.8 (0.4)	–0.2 to 1.9	.166	0.2 (0.4)	–0.8 to 1.2	>.999
Peak external rotation	0.6 (0.4)	–0.4 to 1.6	.343	0.4 (0.3)	–0.6 to 1.3	.971	0.3 (0.4)	–0.9 to 1.4	>.999
ROM	–0.4 (0.4)	–1.4 to 0.6	.876	–0.5 (0.4)	–1.5 to 0.5	.624	0.1 (0.4)	–0.9 to 1.1	>.999
Knee									
Sagittal plane									
CF	–1.4 (1.0)	–4.1 to 1.2	.526	–1.6 (0.9)	–3.9 to 0.8	.293	0.2 (0.7)	–1.8 to 2.1	>.999
Peak flexion	1.6 (1.0)	–1.0 to 4.3	.360	–1.1 (0.7)	–2.8 to 0.7	.394	2.7 (0.6)	1.0 to 4.4	.002[b]
ROM	3.2 (1.0)	0.5 to 5.8	.016[b]	0.5 (1.0)	–2.3 to 3.3	>.999	2.7 (0.7)	0.7 to 4.6	.007[b]
Frontal plane									
CF	–1.2 (0.2)	–0.6 to –1.8	<.001[b]	–1.0 (0.3)	–0.3 to –1.7	.005[b]	–0.2 (0.1)	–0.2 to 0.5	.521
Peak abduction	0.9 (0.3)	0.1 to 1.7	.023[b]	0.7 (0.3)	–0.2 to 1.6	.170	0.2 (0.3)	–0.6 to 1.0	>.999
ROM	0.3 (0.3)	–0.5 to 1.2	.919	–0.4 (0.4)	–1.4 to 0.6	.955	0.7 (0.4)	–0.4 to 1.8	.319
Transverse plane									
CF	5.8 (0.5)	4.5 to 7.0	<.001[b]	5.8 (0.6)	4.1 to 7.4	<.001[b]	0.0 (0.5)	–1.2 to 1.2	>.999
Peak internal rotation	3.2 (0.4)	2.1 to 4.3	<.001[b]	3.8 (0.6)	2.3 to 5.2	<.001[b]	–0.5 (0.4)	–1.5 to 0.5	.513
ROM	–2.5 (0.5)	–3.9 to –1.2	<.001[b]	–2.0 (0.4)	–3.2 to –0.9	.001[b]	–0.5 (0.2)	–1.1 to 0.0	.062
Ankle									
Sagittal plane									
CF	–0.6 (0.6)	–2.2 to 0.9	.865	–0.6 (0.4)	–1.8 to 0.5	.500	0.0 (0.4)	–1.1 to 1.1	>.999
Peak dorsiflexion	0.9 (0.6)	–0.6 to 2.4	.417	–0.9 (0.5)	–2.2 to 0.4	.222	1.8 (0.4)	0.7 to 2.9	.002[b]
ROM	1.5 (0.5)	0.3 to 2.7	.015[b]	–0.3 (0.5)	–1.7 to 1.1	>.999	1.8 (0.4)	0.7 to 2.9	.002[b]
Frontal plane									
CF	0.1 (0.2)	–0.5 to 0.8	>.999	0.4 (0.2)	–0.2 to 0.9	.260	0.3 (0.2)	–0.4 to 0.9	.872
Peak eversion	0.4 (0.3)	–0.3 to 1.2	.513	0.4 (0.2)	–0.2 to 1.0	.232	0.0 (0.2)	–0.6 to 0.6	>.999
ROM	0.2 (0.3)	–0.7 to 1.0	>.999	0.0 (0.2)	–0.6 to 0.7	>.999	0.1 (0.2)	–0.5 to 0.8	>.999
Transverse plane									
CF	3.7 (0.6)	2.2 to 5.2	<.001[b]	4.2 (0.6)	2.5 to 5.9	<.001[b]	–0.5 (0.4)	–1.7 to 0.7	.851
Peak external rotation	2.1 (0.6)	0.5 to 3.6	.010[b]	2.6 (0.6)	0.9 to 4.3	.002[b]	–0.6 (0.6)	–2.1 to 0.9	.999
ROM	–1.6 (0.5)	–3.1 to –0.2	.025[b]	–1.6 (0.3)	–2.5 to –0.7	.001[b]	–0.1 (0.4)	–1.0 to 0.9	>.999

[a]Positive values indicate increased flexion in the sagittal plane, increased adduction/inversion in the frontal plane, and increased internal rotation in the transverse plane. CF, commencement of knee flexion; MD, mean difference; ROM, range of motion.

[b]Statistically significant difference between taping conditions ($P < .05$).