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Research Article

Fluoroscopic Imaging Allows Quantification of Changes in Patellar Tracking due to Taping in Subjects with Patellofemoral Pain

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Abstract

Background: A common clinical evaluation of patellar instability is the J sign, which is a lateral deviation of the tracking of the patella as the patient approaches full knee extension; however, no practical clinical tool is available to quantify levels of lateral deviation.

Methods: The purpose of this study was to evaluate the capacity of a unique fluoroscopic video imaging method to assess changes in patterns of patellar tracking after the application of kinesiology tape in patients with patellofemoral pain exhibiting patellar maltracking. Four subjects (1M, 3F) with patellofemoral pain and diagnosed with patellar maltracking participated in this study. The patellofemoral kinematics with and without kinesiology taping were investigated via a quantitative analysis of fluoroscopic video images using a 5mm spherical stereotactic marker to visualize the patellar centroid during isokinetic knee extension. Visual comparisons of changes in trajectory and medial-lateral displacements were used to evaluate the imaging technique.

Results: Using our fluoroscopic video imaging technique we were able to track the movement of the patella throughout the knee extension exercise and compare the degree of patellar lateral displacement with and without taping.

Discussion/Conclusion: We conclude that this technique may prove to be an important quantitative tool for assessing patellar maltracking and encourage further research.

Keywords: Patellar Maltracking; Kinesiology Tape; Fluoroscopic Image Analysis

Introduction

Patellofemoral pain (PFP) is one of the most common conditions affecting younger, physically active individuals. It has been estimated that about 2.5 million runners will be diagnosed with PFP annually [1] and that the majority of these will be women [2]. Although the source of this pain is considered multifactorial [3], the primary theory is that it develops from abnormal gliding (lateral malalignment) of the patella or patellar maltracking [4].

Palmieri et al. [5] stated that all knee joint pathology results in weakness of the muscles surrounding the knee joint complex; however, the severity of these weaknesses may vary due to the degree of joint damage, the time since the injury occurred, and the knee joint angle and associated levels of athrogenic muscle inhibition [6]. Additionally, the association between overall quadriceps strength and PF joint mechanics during leg extension among PFP patients is low [7]. PFP patients have demonstrated: (1) decreased tension of vastus medialis oblique (VMO) tendon [8]; (2) muscle imbalance between VMO and vastus lateralis (VL) [9]; and, (3) a delayed VMO onset time when compared to VL onset time [10]. These findings suggest that reduced muscle size (atrophy) [11] and quadriceps muscle strength deficits [7] may not be causes of PFP; however, imbalances in strength or firing patterns of these muscles may cause lateral maltracking resulting in PFP. Clinically, the most common method of assessing patellar maltracking is through visual assessment and palpation using four components, glide, tilt, rotation and anterior-posterior tilt [4]; however, this technique is subjective and somewhat inconsistent because it cannot objectively quantify the degree of displacement [12]. A number of imaging technologies such as computer tomography scans and magnetic resonance imaging [13-16]have been used separately and in combination with model-based tracking [16-19] to provide a more quantitative assessment of patellar tracking with varied success; but the main disadvantages are inconvenience, cost, and in the case of computer tomography and other radiographic techniques, radiation [20]. Additionally, patellar maltracking has been assessed kinematically using custom-made devises such as molded patellar caps [21]. Dynamic fluoroscopy may provide a more feasible assessment tool for patellar tracking throughout a knee range of motion due to its lower cost, portability and reduced exposure to radiation for the patient.

The purpose of this case study was to evaluate the capacity of a unique fluoroscopic video imaging method to evaluate changes in the patterns of patellar tracking resulting from the application of kinesiology tape in patients with PFP exhibiting patellar maltracking. The use of adhesive tape to correct apparent maltracking of the patella and improve patient symptoms is a common approach in the treatment of PFP. Historically, non-elastic tape applications, such as McConnell taping [14, 22-26], have been most commonly utilized for this purpose; however, more recently the application of elastic tapes such as kinesiology tape has become increasingly popular in the clinical setting [27-30]. It has been proposed that kinesiology tape can assist in improving patellar tracking and reduce patient symptoms by facilitating quadriceps function to improve dynamic stability of the patella [31, 32]. We therefore hypothesized that our novel fluoroscopic assessment technique would detect changes in patellar tracking resulting from the application of Upper Knee Spider™ Kinesiology tape (UKS) (SpiderTech Inc., Toronto, Canada) in subjects suffering from PFP. The SpiderTech Upper Knee Spider precut system has been reported to have the capacity to support injured knees, reduce associated pain, and improve the healing process. It is further argued that SpiderTech tape provides dynamic therapeutic support for the restoration of functional joint stability through neurosensory mechanisms. And finally, its consistent size and shape allow effective targeting the knee musculature [33].

In order to test this hypothesis, the effect of UKS on patellar kinematics of subjects presenting patellar maltracking was investigated. For the purpose of this investigation maltracking was defined as a condition where the patella does not remain within the central groove of the femur, but tilts and moves laterally. More specifically, the relative motion of subjects' patellae with respect to their femurs during knee flexion-extension was tracked via fluoroscopic images. The patellar trajectories obtained with and without wearing UKS were compared, and the changes in patellar motion patterns due to the use of the tape were assessed.

Methods

The procedures and methods used in this study were approved by the Subcommittee for the Use and Protection of Human Subjects at the University of Miami. All participants were informed of the purpose of the study and experimental procedure of the study and provided written consent. A flow chart showing the experimental design is presented in Figure 1.

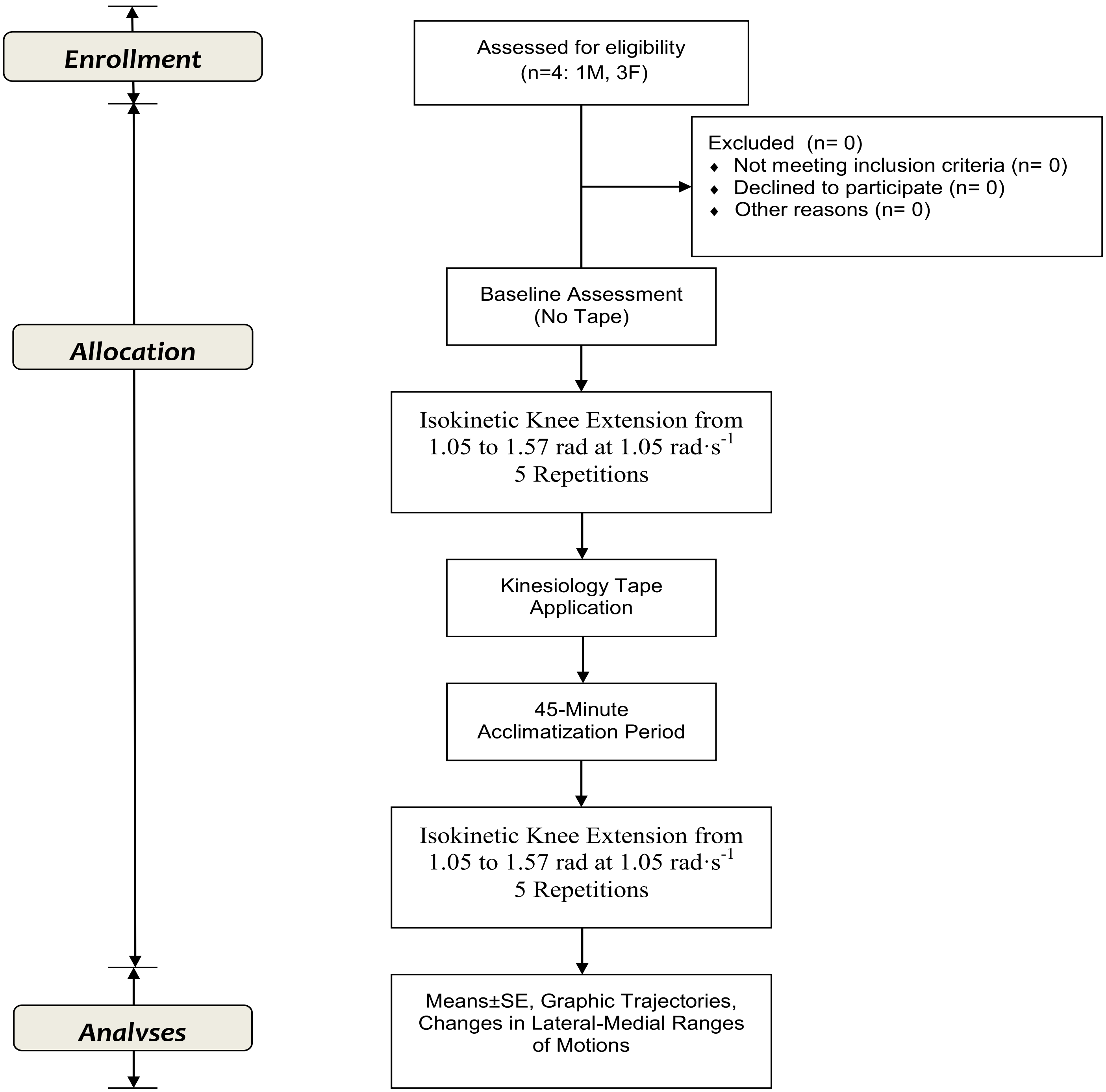
Participants

A total of 4 subjects (1 male and 3 females), aged eighteen to twenty-five, volunteered for this study. Subject characteristics are presented in Table 1. Participants were included if they were recreationally active with no history of previous knee surgery to the involved knee and were currently suffering from PFP. In this study, PFP was defined as a reasonable clinical probability of patellar maltracking using the J-sign, pain greater than 4.0cm in the anterior portion of the knee during physical activity using a 10.0 cm visual analog scale, and pain during at least two of the following activities: stair ascent or descent, squatting, kneeling, prolonged sitting, or isometric quadriceps contraction. A certified athletic trainer performed a clinical evaluation and confirmed that all of the participants in this study were likely experiencing lateral patellar maltracking as indicated by J-sign [12]. Participants were excluded if they had a history of lower extremity surgery, knee ligamentous instability, patellar instability, patellar tendonitis or an allergy to adhesive tape. The average length of time participants experienced symptoms was 3.5±1.9 y (mean±SD).

Experimental setup

Subjects sat securely on a Biodex® apparatus (System 4 Pro, Biodex Medical Systems, Inc. Shirley, NY) with the hips and knee flexed to 1.40 and 1.05 rad, respectively. These angles

Figure 1. Flow chart of experimental procedures.



were dictated by the interactive environment between the fluoroscope and dynamometer, respectively. Starting from a knee flexion angle of 0.52 rad, participants were asked to complete a knee extension through their individual full ranges of motion at 1.05 rad•s^{-1}. All participants completed 5 trials with a two to three minute recovery between trials.

Table 1. Participant demographics.

Subject	Age (y)	Height (m)	Weight (kg)	VAS (cm)	Symptom Duration (y)
1	24	1.61	55.1	4.8	3
2	21	1.77	68.2	5	1
3	19	1.57	51.4	5.4	5
4	21	1.76	61.2	4.7	5
Mean (SD)	21.3 (2.6)	1.68 (.10)	59.0 (7.4)	5.0 (0.3)	3.5 (1.9)

Fluoroscopic Imaging

During the knee extension task, the trajectory of the patella was tracked via fluoroscopic video images. This was accomplished by positioning a c-arm fluoroscope (Fluoroscan Mini Premiere Encore, Hologic, Inc., Bedford, MA, USA) with its plane of view parallel to the coronal plane of the femur. During knee motion, fluoroscopic video images were collected at a rate of 30 frames per second. A spherical stereotactic marker of 5mm diameter was also captured in the fluoroscopic images to allow conversion of the computed distances from pixels to millimeters. Quantitative information on patella trajectory was obtained via in-house Matlab®-based (MathWorks®, Natick, MA, USA) software developed for fluoroscopic image analysis as reported below.

Upper knee Spider™ kinesiology tape intervention

Following the first set of 5 trials, the UKS system was applied (Figure. 1.). Before applying the tape, the subject's knee was positioned in 1.57 rad of flexion. The base of the tape was applied with no tension (0% stretch) to the knee just below the patella, while the remaining taping pattern was applied following the taping pattern with between 50-75% of maximal tension on the elastic tape (Figure. 1). The UKS was applied by professional clinicians who were trained by the Spider-Tech. Participants were given approximately 45 minutes to become accustomed to the taping condition after which the knee extension task was repeated as described previously (Figure. 2). Supporting the effectiveness of the kinesiology taping, participants reported a decline in visual analog pain scores from 4.95±0.67cm to 3.19±1.28 cm.

Figure 2. Completed Upper Knee Spider™ application. Each subject received a Kinesiology tape application using a pre-cut Upper Knee Spider tape™.

Fluoroscopic image analysis

In order to quantitatively analyze patellar trajectory, in each set of video images, the location of the centroid of the patella was referred to a fixed reference frame defined by anatomic landmarks of the knee. More specifically, using a livewire approach,[34] the contour of the patella was segmented, and its center of mass was considered as the patellar centroid. For each image, the position of the patellar centroid was referred to a frame of reference defined as follows: the x-axis was delineated by the two femoral epicondyles (positive direction being medial-to-lateral); the y-axis was orthogonal to the x-axis, and passed through the midpoint of the femoral epicondyles (positive direction being distal-to-proximal).

Figure 3. Experimental setup: subjects are secured on a Biodex® apparatus. During knee flexion-extension, patellar motion is imaged via a c-arm fluoroscope.

A single individual was responsible for determining, in each fluoroscopic image, the patellar contour and the locations of femoral epicondyles individuating the frame of reference. A sample image showing the patellar centroid together with knee reference frame is presented in Figure. 3. Based on patellar trajectory, for each experimental trial analyzed, the medial-lateral displacement of the patella was calculated.

Statistical analysis

For each participant, means and standard deviations for displacements were calculated for all trials performed with and without UKS. The differences in displacements with and without UKS were also computed, and reported as percentage variation with respect to the case in which no taping condition was applied to the knee. A paired *t*-test was used to determine differences between with and without UKS conditions. The differences between mean patellar displacements were reported with 95% confidence intervals. Subsequently, a Levene's test (□=0.05) was used to check the equality of the variances obtained with and without UKS.[35] All statistical computations were performed in Minitab® 16 (Minitab Inc., State College, PA).

Results

The total medial-lateral displacement of the patella was reduced following the application of UKS tape (Table 2).

Table 2. Differences in patellar medial-lateral ROM with and without UKS tape.

Subject	Difference (mm)	Difference (%)
1	4.4±2.6	51.3±30.7
2	0.7±2.3	14±46
3	1.7±3.3	17.7±18.6
4	4.5±3.3	38.5±28.7

Data are reported as 95% confidence interval. The percentage difference is reported with respect to the case without UKS.

Table 3. Patellar motion with (w/) and without (w/o) UKS tape.

Subject #	ROM w/o KT (mm)	ROM w/ KT (mm)	Ratio of Variances
1	8.5±1.2	4.8±1.1	0.93
2	5.0±0.7	4.3±0.57	0.80
3	9.7±0.9	8.0±0.7	0.79
4	11.6±0.9	7.1±1.2	1.25

Data are reported as mean and standard deviation of medial-lateral range of motion (ROM).

In addition, patellar trajectories shifted in the medial direction following the application of UKS when compared to those without UKS (Table 3). Representative patellar motion patterns for Subject #1 are illustrated in Figure. 4. For each subject, the Levene's test for equality of variances indicated no difference in variances of displacements attained with or without UKS (P > 0.05) in Table 3.

Figure 4. Representative fluoroscopic video image of patellar tracking. The patella contour (green line) and its centroid (green circle) are shown, together with the contour of the stereotactic marker (blue dotted line). The reference frame of the knee is individuated by the medial-lateral axis (x-axis) passing by the two femoral epicondyles (purple dots), and the proximal-distal axis (y-axis) passing by the midpoint of the x-axis.

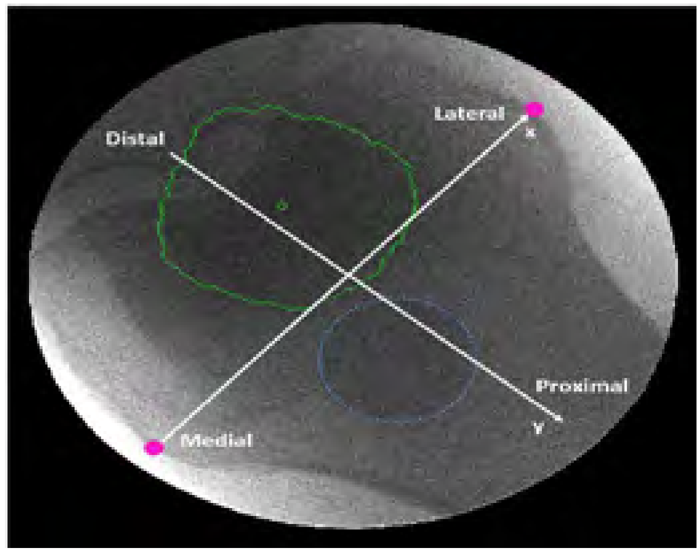


Figure 5. Representative patella's trajectories along the femoral trochlea obtained with (dash line) and without UKS tape (solid line) for subjects 1 (a), 2 (b), 3 (c) and 4 (d). All the data reported in the figure refer to flexion-extension trials of each subject.

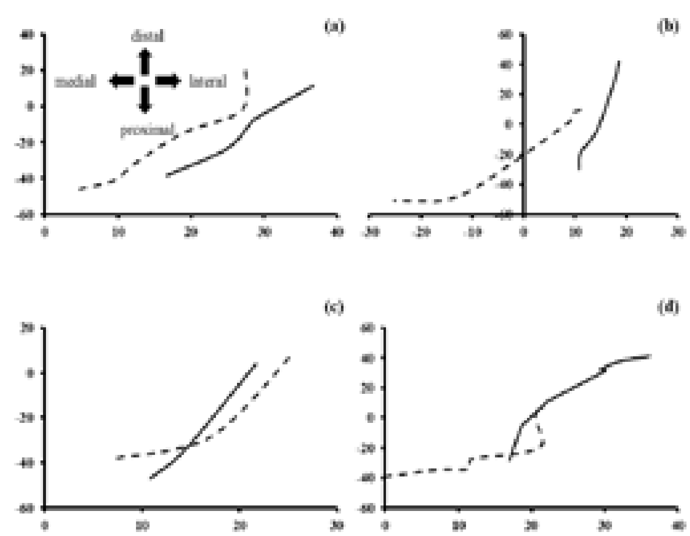
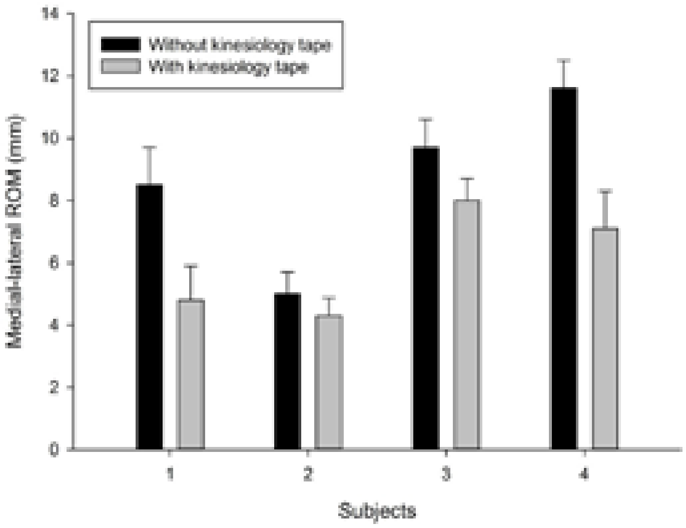


Figure 6. Means±SD for medial-lateral range of motion for leg extensions with and without kinesiology tape.



Discussion

Abnormal kinematics of the patellofemoral joint, most commonly described as the 'J-sign', have been described in patients with patellofemoral pain.[36] There are several potential causes for this abnormal motion pattern including quadriceps weakness and imbalanced activation of the quadriceps.[37-39] We found that patellar trajectories shifted medially after application of UKS when compared to those without UKS application. In addition, when medial-lateral patellar displacements were compared, we found that total displacement was reduced in all participants during the UKS compared to the non-UKS condition. These data reflect results reported by a number of researchers who have examined the impact of taping on patellar trajectories in persons with PFP. For example, in an MRI study, Derasari et al. 14] noted that McConnell taping produced a significant patellofemoral inferior shift in PFP patients with the greatest shift being in lateral-medial displacement. The magnitude of the change in displacement varied from subject to subject (from 4.46 mm to 0.71 mm). This was partly due to the different sizes of the knees of the subjects. Accordingly, displacement differences were reported as percentage change with respect to non-UKS tape condition (Table 3), and the estimated reduction of medial-lateral displacement was up to 51% when UKS was applied. These findings suggest that the use of UKS mitigates the pathological lateral drift of subjects' patellar motion. These qualitative findings on patellar trajectories were corroborated by a quantitative analysis of the difference in patellar medial-lateral displacement found with and without UKS. The medial-lateral displacement was consistently reduced when UKS was applied.

These results may be explained by tactile input generated by applying UKS over the joint surface. Convolution (small waves in the tape that are thought to put tension on the skin) areas underneath applied UKS may increase interstitial spaces between the skin and muscle and may result in increased the flow of blood and lymphatic fluids. This increased blood circulation is theorized to provide positive impact on muscle function[40, 41] and performance.[42, 43] In addition, previous studies have shown that application of tape or neoprene sleeve garments to the knee joint have a facilitatory effect on quadriceps muscle function in the presence of previous knee injury.[44, 45, 46] This is thought to be related to the stimulation of mechanoreceptors in the skin which has been shown to reduce both pain driven and more broadly arthrogenic muscle inhibition of the quadriceps.[44, 46, 47] Therefore, the taping pattern utilized in this study may have led to improved muscle function and reduced pain, both of which likely had a positive impact on patellar tracking in these subjects.

A few assumptions may affect the results of this analysis. The motion of the patella was monitored via 2D images collected in the coronal plane of the knee. Accordingly, computations of patellar trajectories were performed assuming that the patella glides on femoral trochlea within the plane of view of the fluoroscope. In reality, patellar motion out of plane, although not dramatic, may occur. This may affect the accuracy in determining the location of patella's centroid with respect to the femur. Hence, the actual patellar trajectories might differ from those reported in this study. Moreover, the sample size used in this analysis was limited to four subjects. Accordingly, a larger sample size might be needed in order to provide a more quantitatively accurate estimate of the improvements in patellofemoral kinematics attained with UKS.

A number of imaging methods have been used to assess patellar tracking. Compared to the fluoroscopy technique described here, these techniques all share common obstacles that reduce their use in conventional clinical settings such as offices or treatment rooms. First of all, MRI, CT and X-ray assessments require large, dedicated areas and special structural considerations to isolate them from clinical staff or environmental conditions that might affect their function. This differs considerably from the fluoroscopy device used in our assessment which is highly portable and requires no special environment for its use. Second, the costs of these devises and the environments in which they are housed are prohibitive limiting the feasibility of their use in most clinics, offices and rehabilitation facilities. When comparing our methodology to other techniques a number differences specific to the technique concerned. For example, using biplanar x-ray imaging in conjunction with model-based tracking, Bey et al., [17] were able to measure patellofemoral joint movement in vivo. While the authors reported that their technique could accurately provide 3-dimensional movement patterns during functional activities, they noted a number of disadvantages to its use. Primary among these was that the level of x-ray exposure required greatly limits the number of trials that can be performed. Additionally, the field of view was limited by the nature of the biplanar x-ray device. Using MRI to assess three-dimensional patellar tracking patterns, Fellows et al. [16] noted that they could accurately evaluate 3D patellar tracking using a series of static images. In addition to the static nature of this assessment, the time necessary for the assessment was

Conclusion

As noted by Powers et al. [3], clinical diagnostic tests need to be developed that allow quantification potential pathological parameters that lead to PFP. Specifically, simple clinical tests for the classification of patients' needs would facilitate targeted patient-specific treatment options. As part of this, the relationship between complex imaging and modeling techniques should be related to more available clinical measures. Further development of imaging modalities (e.g., MR spectroscopy, water-fat differentiating MRI, PET, CT), and other tools that will enhance the diagnosis of underlying mechanisms of PFP, is needed.

This is the first study to illustrate the effect of UKS on patellar maltracking using a quantitative fluoroscopic approach throughout a full knee extension. Our results suggest that UKS may improve the medial-lateral tracking abnormalities commonly describe in patients with PFP. The findings of this study corroborate the body of literature reporting the benefits of kinesiology tape, and suggest that such tape may represent a viable tool for therapy when pathological patellofemoral joint biomechanics leads to PFP. Additionally, the use of fluoroscopy may prove an important quantitative tool for assessing patellar maltracking. Therefore, this study should be repeated using a much larger sample of patients with varying levels of pain and other clinical presentations so that normative values can be developed, thereby increasing the diagnostic value of this methodology.

Conflicts of Interest

The authors confirm that they have no conflicts of interest.

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