Journal of Electromyography and Kinesiology 14 (2004) 495–504

JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY

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Patellar taping increases vastus medialis oblique activity in the presence of patellofemoral pain

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Received 21 April 2003; received in revised form 22 July 2003; accepted 3 October 2003

Abstract

A common rehabilitation strategy for patellofemoral pain syndrome (PFPS), which lacks scientific evidence, includes pulling the patella medially with tape to reduce pain and increase the vastus medialis oblique (VMO) muscle activity. The purpose of this study was to examine the effect of various patellar taping procedures on force production, EMG activity of the VMO and vastus lateralis (VL) muscles, and perceived pain experienced by 30 women (27.3 ± 1.53 years), half diagnosed with PFPS. The perceived pain, force, and EMG of the VMO and VL, were recorded while subjects performed maximal isokinetic leg presses at 30°/s for each of the following patellar taping conditions: no tape (control), no glide (placebo), medial and lateral glide (experimental). The medial and placebo procedures significantly ($P < 0.01$) reduced perceived pain (70–80%) in PFPS subjects. Although patellar taping did not influence leg press force ($P > 0.05$), it increased the VMO activity and decreased the VL activity in PFPS subjects but had the opposite effect in healthy subjects. The findings suggest that taping the patella medially can contribute positively to PFPS rehabilitation. Because the medial glide and placebo taping conditions had similar effects, it is proposed that the benefits of patellar taping are not due to a change in patellar position but rather due to enhanced support of the patellofemoral ligaments and/or pain modulation via cutaneous stimulation.

Keywords: VMO; VL; Force; Perceived pain; Leg press

1. Introduction

The major complaint of individuals with patellofemoral pain syndrome (PFPS) is anterior knee pain or pain behind the patella (retropatellar pain) and is experienced usually during running, squatting, and stair climbing [22,31,35]. The occurrence of patellofemoral pain is two to three times more prevalent in women compared with men [27]. Numerous biomechanical characteristics of the lower body such as decreased joint flexibility, large quadriceps angle (Q-angle), and increased subtalar joint pronation have been proposed to explain its onset [9,13]. Nonetheless, the leading etiological factor is a decline in the activation of the vastus medialis oblique (VMO) muscle [22,31]. Anatomically, the VMO attaches at a 40–55° angle to the long axis of the femur on the medial side of the patella [15]. The functional importance of the VMO, therefore, is to dynamically stabilize the patella on the medial side and prevent lateral deviation and rotation of the patella caused by the lateral pull of the larger vastus lateralis (VL) muscle [16,28].

A common rehabilitation strategy to alleviate patellofemoral pain and improve patellar tracking within the trochlea of the patellofemoral joint includes taping of the patella, stretching of tight lateral structures, correction of lower body biomechanics, and selective quadriceps exercises to increase the activity of the VMO [8,9]. The use of tape became popular following McConnell's original publication [28], which proposed that pulling the patella medially with tape (medial glide) will correct the patella position, stretch the tight lateral structures, increase the activity of the VMO muscle, decrease pain and thus allow the patient to begin strengthening exercises of the quadriceps.

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doi:10.1016/j.jelekin.2003.10.007

Since McConnell's proposition [28], a number of studies examined whether external means such as tape or braces can correct the patella position. Patellar taping appears to significantly reduce perceived pain levels, however, this reduction in pain is associated with minimal [25,32,36] or no change in patellar position [6]. Similarly, numerous patellar braces reduce pain with minimal or no change in patellar position [8,30].

Accumulating evidence, therefore, suggests that the success of taping (and bracing) to reduce pain may not be due to altering the patellar position but rather due to a neurophysiological factor. For example, taping the patella in a medial or lateral glide compared with no taping increased the VMO activity during a knee extension task in patients with PFPS [34]. The onset of the VMO activity in a stepping task, furthermore, appears to be faster than that of the VL when the patella was pulled medially with tape [7,14].

The effectiveness of patellar taping on the VMO activity of individuals suffering from PFPS is unclear. Support for the use of patellar taping to alter the activity of the VMO muscle comes from either not well-controlled studies using single-joint tasks [35] or directly from McConnell's research group [7,15,29]. To date, no study has systematically examined the effects of taping the patella in various directions on the magnitude of VMO activity and perceived pain, especially during a velocity controlled multi-joint movement [9].

The purpose of this investigation was to determine whether patellar taping could alter the isokinetic leg press force production, EMG activity of the VMO and VL muscles, and perceived pain experienced by women with and without patellofemoral pain.

2. Methods

2.1. Subjects

Thirty young active women (27.3 ± 1.53 years) volunteered for this study. Fifteen of the participants were diagnosed by the same physician with unilateral PFPS and had current symptoms, which included only pain behind the patella (retropatellar pain) that increased during activities. The subjects with PFPS also reported that they were unable to run for more than 5 min and have never received any kind of treatment prior to the study. Patients with patellar tendonitis or other anterior knee pain symptoms were excluded. The other 15 women had neither history of previous knee pathology nor any current knee injuries (Table 1). Subjects provided written informed consent prior to participation in the study. The institutional review board for research at the University of Illinois approved the procedures used in this study.

Table 1
Anthropometric measurements for healthy women and women with patellofemoral pain (symptomatic and asymptomatic knees)

	PFPS group		Healthy group
	Symptomatic (*n*= 15)	Asymptomatic (*n*= 15)	Healthy (*n*= 30)
Age (years)	26.3 ± 1.53		28.4 ± 1.52
Height (m)	1.66 ± 0.02		1.65 ± 1.04
Mass (kg)	60.8 ± 1.36		61.3 ± 1.12
Supine Q-angle (°)	21.9 ± 1.37	22.8 ± 1.23	21.8 ± 1.01
Hamstrings flexibility (°)	66.7 ± 2.50	63.2 ± 2.74	73.9 ± 1.33
Gastrocnemius flexibility (°)	16.6 ± 1.35	15.1 ± 1.31	16.3 ± 0.77
Soleus flexibility (°)	19.9 ± 1.30	20.5 ± 0.95	19.1 ± 1.01
Rearfoot pronation (°)	5.33 ± 0.71	4.41 ± 0.77	4.03 ± 0.47
Rearfoot supination (°)	0.13 ± 0.13	0.27 ± 0.27	0.07 ± 0.07

2.2. Experimental setup

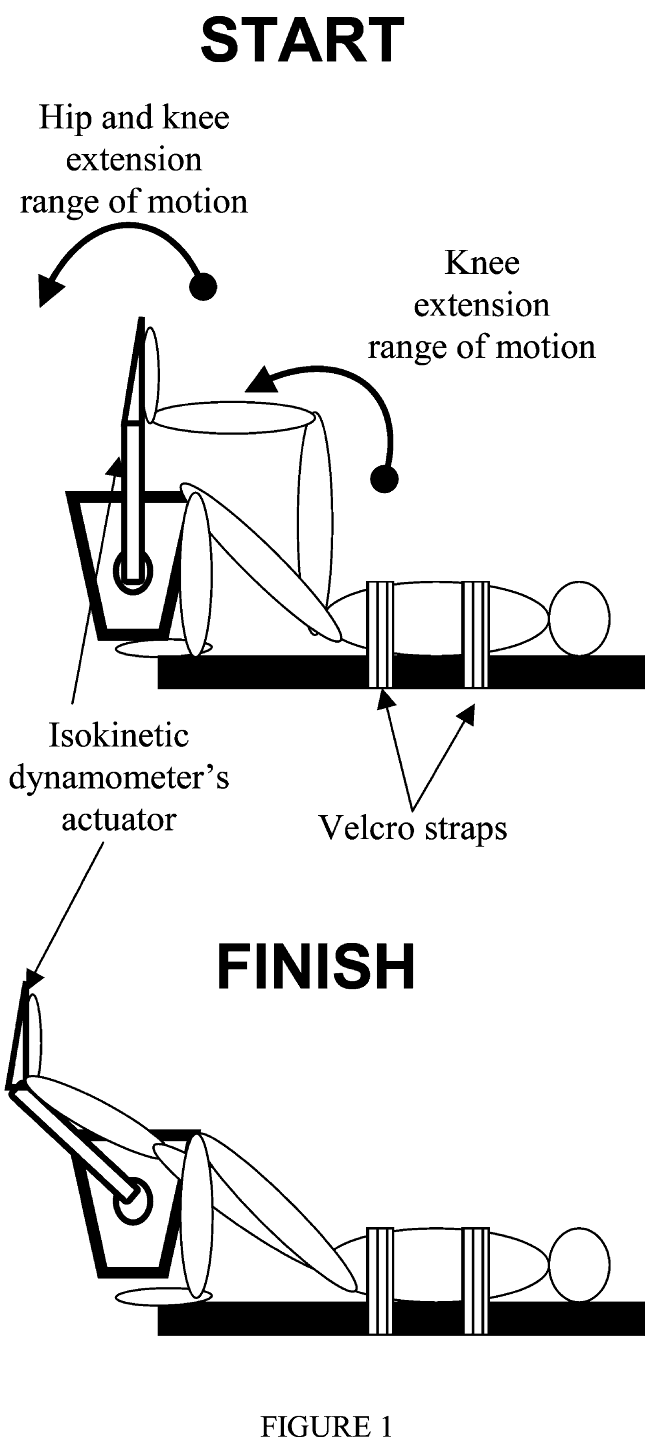
All subjects laid supine on the isokinetic dynamometer's (KIN-COM) flat bench and positioned the tested limb on the dynamometer's arm (Fig. 1). The upper body was restrained with velcro straps. All trials started with the knee and hip joints flexed at 90°, and each participant extended the knee to 0° (full knee extension). The hip extension range of motion (ROM) was approximately half of the knee joint ROM and varied slightly among subjects. Therefore, to maintain an isokinetic knee extension at 30°/s, the speed of the dynamometer's arm was adjusted based on the knee ROM (see Fig. 1 for details).

2.3. Mechanical and electrical recording

The angular displacement of the knee joint was detected with an electronic goniometer made of two aluminum arms 20 cm long and a 1-turn potentiometer (positioned at the knee axis of rotation). Force production at a near constant velocity during a leg press movement was detected with a KIN-COM 500H (Chattanooga, TN) isokinetic dynamometer. The sampling frequency for the electronic goniometer and force was 100 Hz. The KIN-COM 500H is a reliable way to assess force isokinetically not only during knee extension [2] but also during leg press movements [26].

The muscle activation (EMG) of the VMO and VL muscles (both legs) was measured with Beckman 4 mm silver–silver chloride surface electrodes. A bipolar electrode configuration was used for both muscles and was referred to another electrode that was placed over noncontracting tissue (bony surface of the tibia 3 cm below the tibial tuberosity). For the VMO, the electrodes were placed 4 cm superior and medial to the superior–

medial border of the patella, whereas for the VL the electrodes were placed 10 cm superior to the lateral epicondyle of the femur. The area where the recording electrodes were placed was shaved, lightly abraded, and cleaned with alcohol. The EMG signals were amplified (×1000) using an isolated bioamplifier (S-series, Coulbourn, USA), filtered (10–1000 Hz) using an adjustable bandpass filter (S-series, Coulbourn, USA), and sampled at 1000 Hz (12-bit analog to digital converter). Output from the bioamplifiers was processed using Coulbourn contour following integrators (S-series, Coulbourn, USA) with a time constant of 50 ms. Tektronic oscilloscopes were used to monitor signals during data collection. The amplitude of the signal was computed as the average rectified EMG (AEMG) of two trials from nine different angle bins (90–80°, 80–70°, 70–60°, 60–50°, 50–40°, 40–30°, 30–20°, 20–10°, and 10–0°). All data were normalized to maximum AEMG values obtained when the knee was not taped (control condition). This procedure allowed for comparisons to be made between the two groups of subjects. The EMG signal was collected, stored, displayed and analyzed on a personal computer using custom made software.



2.4. Patellar taping

For the patellar taping, a Leukotape 1.5 in. high adhesive tape (Belersdorf Inc. Norwalk, CT) designed specifically for the treatment of PFPS was used. For all taping procedures (Fig. 2), two 8-in. long strips of the Leukotape were used. For the medial glide, the first strip of tape originated at the fibular head and was pulled over the lower half of the patella with a medial force terminating at the pes anserinus. The second strip of tape originated from the same point and terminated on the pes anserinus but was taped 0.75 in. higher. For the lateral glide, the same procedure was followed but the origin was the pes anserinus and the termination point was the fibular head. The force was applied laterally. For the no glide procedure, the pes anserinus and fibular head served as the two endpoints for the tape. The tape was applied using both hands at the same time with no direction given to the patella. All forces applied in either direction were equal to the maximum stretch allowed by the Leukotape high adhesive tape. For all taping procedures, the tape was applied directly on the skin and no adherent spray was used. The author of the study performed the taping procedures to all subjects.

Fig. 1. Subject positioning on the isokinetic dynamometer to perform leg press movements. The hip and knee joint started the movement flexed at 90°, however, only the knee joint extended to 0° (full extension). To calculate the appropriate velocity for the dynamometer's arm and achieve a near constant velocity for the knee joint at 30°/s, the ROM of the arm produced by the leg press (hip and knee extension of the subject) was divided by 3 s. For example, if a subject moved the dynamometer's arm 81° during the leg press movement, the isokinetic velocity was set at 27°/s. Therefore, the knee ROM (90°) was accomplished within 3 s or at an isokinetic velocity of 30°/s. The ROM for the hip joint was approximately half of that of the knee and varied slightly among subjects (45 ± 2.3°), as a result, the isokinetic velocity for the hip joint was slower compared with that of the knee (~15°/s).

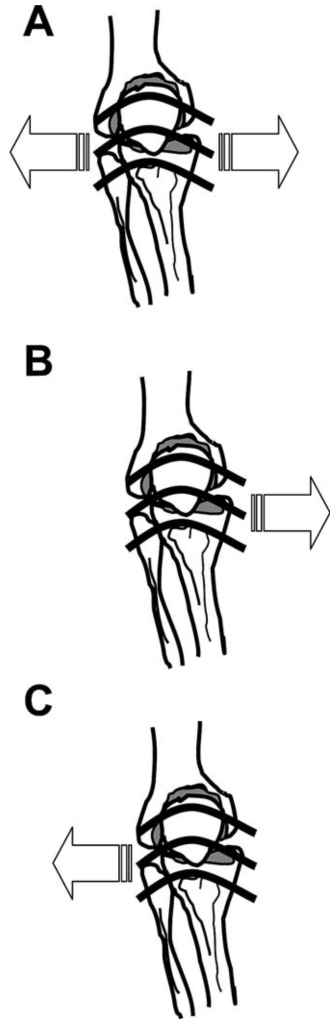


Fig. 2. The placebo (A), and two experimental taping procedures (B and C). For the control condition, no tape was applied, whereas for the placebo (A) procedure tape was applied, but no direction was given to the tape. For one of the experimental procedures, the direction of the tape produced a medial pull on the patella (medial glide; B), whereas the other experimental procedure produced a lateral pull on the patella (lateral glide; C). See Methods for more details.

2.5. Anthropometric measurements

The height and weight of all subjects were measured first. For the measurement of the Q-angle, the participants lay supine on a table with the lower extremity relaxed. Marks were placed on the anterior superior iliac spine and tibial tuberosity. A goniometer with long arms was used. The axis of rotation of the goniometer was placed over the knee joint, one arm was aligned with the tibial tuberosity (leg) and the other with the anterior superior iliac spine (thigh). Q-angle was defined as the angle (medial side) between the thigh and the leg.

For the hamstring flexibility measurement, the participants lay supine on a table with the lower extremity relaxed. The tester moved the thigh into 90° of hip flexion with the knee joint relaxed. The participants were asked to raise their lower leg as slowly as possible to form a straight line with the thigh. When they could not produce any more movement, one arm of the goniometer was aligned with the head of the femur and the other with the fibula. For the gastrocnemius and soleus flexibility measurement, the participants also lay supine on a table. To determine the gastrocnemius (bi-articular muscle that crosses the knee joint) flexibility, the subjects were asked to dorsiflex their foot as much as possible while the knee was kept extended. For the soleus (uni-articular muscle that does not cross the knee joint) flexibility measurement, however, prior to the dorsiflexion, the tester moved the thigh into 90° of hip flexion and held the lower leg at a 90° angle with the thigh. In both measurements, when subjects could not produce any more dorsiflexion movement, one arm of the goniometer was aligned with the 5th metatarsal and the other with the fibula.

For the rearfoot position (pronation/supination) measurement, the subjects stood on a board that was placed on the examining table. Marks were placed on the mid calcaneus and mid achilles tendon, and were joined by a straight line that connected the two marks. One arm of the goniometer was placed parallel to the ground and the other was placed along the line. The angle formed −90 was the pronation or supination angle.

2.6. Experimental protocol

Each subject attended one testing session. Immediately prior to data collection, subjects were given a written summary and verbal information regarding testing procedures. After the subjects signed the consent form, they also filled out a knee injury history questionnaire. Prior to the leg press task and EMG setup, the anthropometric measurements mentioned previously were taken.

All leg press trials started with the knee and hip joint flexed at 90°, and the subject extended the knee to 0° (full knee extension) at an isokinetic velocity of 30°/s. Pilot testing suggested that this slow to moderate velocity was the best for a controlled leg press movement on the isokinetic dynamometer. Faster movements easily changed the leg position and slower movements were not functionally representative. Subjects were given warm-up trials at 30°/s until they felt comfortable to produce a maximum trial (all participants performed less than 10 trials). All warm-up trials were submaximal efforts and served as a warm-up and acclimatization period with the isokinetic dynamometer. To assess perceived pain after every trial, each subject rated her level of comfort with a modified McGill analog pain questionnaire. The McGill pain questionnaire has been used extensively in the past and has shown to be reliable [11,12].

After the acclimatization period and a rest period of 5 min, each subject performed two maximum isokinetic trials at 30°/s. Leg press movements were recorded for 5 s (most contractions ended close to 3 s because of the specified isokinetic velocity of 30°/s for the knee joint). The control (no tape), placebo (no glide), and two experimental conditions (medial and lateral glide) were tested in random order. The order for testing each leg (left or right) was counterbalanced.

2.7. Statistical analysis

The dependent variables included the force produced during the isokinetic leg presses, the AEMG of the VMO and VL muscles, perceived pain, and various anthropometric characteristics of the subjects. The independent variables in this study were the knee status of the subjects (healthy, asymptomatic, and symptomatic), the patellar taping procedures (no tape, no glide, medial glide, and lateral glide) and knee angle (90–80°, 80–70°, 70–60°, 60–50°, 50–40°, 40–30°, 30–20°, 20–10°, and 10–0°). All statistical analyses were performed using SPSS 9.0 statistical package (SPSS Inc., Chicago, IL).

Two basic sets of analyses were performed. First, comparisons were made between the knees of subjects with current unilateral PFPS (PFPS group) to identify whether significant differences existed among the symptomatic and asymptomatic knees (knee status). The second analysis was a between subject comparison of the PFPS group (asymptomatic and symptomatic knees grouped together) and the Healthy group (the left and right knees grouped together). These analyses were performed using a mixed three-factor ANOVA (2 knee status × 4 taping procedures × 9 knee angles), with repeated measures on taping procedures and knee angles. A paired t-test was used to identify any differences in the anthropometric characteristics between the symptomatic and asymptomatic knees within the PFPS group; whereas, an independent t-test was used to examine any differences in the anthropometric characteristics between the PFPS and Healthy groups. The alpha level for all statistical tests was set at 0.05 and independent t-tests were used to locate differences between the Healthy and PFPS groups when ANOVAs yielded significant interactions. When multiple comparisons were used, the Bonferroni correction was employed within a family of comparisons. Data in tables and figures are expressed as mean ± SEM.

3. Results

3.1. Symptomatic and asymptomatic knee differences

The anthropometric characteristics for the symptomatic and asymptomatic knees within the PFPS group are in Table 1. Paired t-tests between the symptomatic and asymptomatic knee revealed that only hamstring flexibility approached significant differences ($t = 2.06$, $P = 0.058$). All other anthropometric characteristics and flexibility measurements were not significantly different ($P > 0.05$).

As expected, performance with the symptomatic knee induced significantly greater levels of pain ($P < 0.01$) (Fig. 3). Taping the patella, furthermore, significantly reduced pain with all experimental procedures. The medial and no glide taping procedures resulted in the greatest decrease in pain compared with the no tape procedure ($P < 0.01$). Although the medial glide taping produced the lowest mean pain level, it was not significantly different from the no glide taping procedure ($P > 0.05$). The lateral glide also decreased pain; however, this decrease in pain was not significant compared with the pain experienced without any tape ($P = 0.06$).

Force production and muscle activation levels were similar ($P > 0.05$) between the symptomatic and asymptomatic knee in subjects with PFPS (Table 2). Although the amount of pain reported by the subjects was greater while using the symptomatic knee, because the physical characteristics (Table 1) and motor performance measurements (force and AEMG) were not

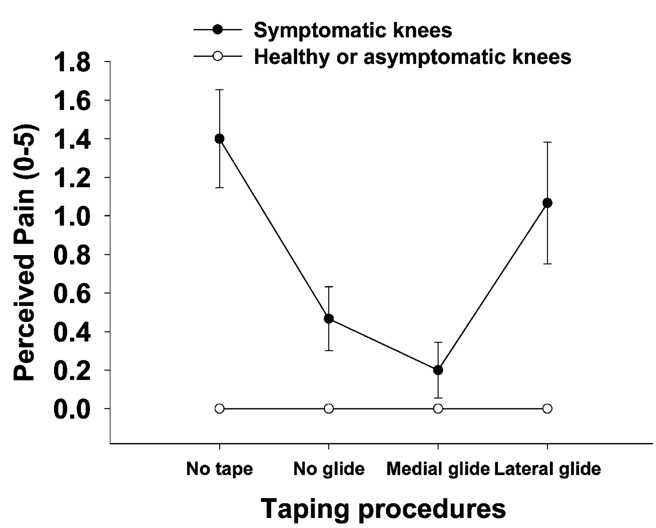


Fig. 3. Perceived pain for the symptomatic knees varied as a function of taping procedure, whereas the asymptomatic and healthy knees experienced no pain. The lowest perceived pain was experienced with the medial glide but it was not significantly different from the placebo procedure (no glide). The lateral glide also decreased perceived pain, however, this reduction in pain was not significant when compared with the pain experienced with no tape (control condition).

Table 2
Peak leg press force (±SEM) for healthy women and women with patellofemoral pain (symptomatic and asymptomatic knees)

	PFPS group		Healthy group
	Symptomatic (n= 15)	Asymptomatic (n= 15)	Healthy (n= 30)
No tape (N)	814.4 ± 206.4	844.2 ± 238.3	742.6 ± 35.1
Placebo (N)	791.5 ± 207.3	782.7 ± 165.9	792.1 ± 33.2
Medial glide (N)	831.6 ± 227.9	751.9 ± 183.4	751.1 ± 41.7
Lateral glide (N)	846.1 ± 220.6	802.1 ± 214.8	743.1 ± 37.3

Note: Peak leg press force occurred consistently at 50–40° knee flexion angle.

significantly different, all 30 knees were grouped together to form the PFPS group and were compared against the 30 healthy knees from the Healthy group.

3.2. Healthy and PFPS group differences

The only anthropometric characteristic that was significantly different between healthy women and women with PFPS was hamstring flexibility ($P< 0.05$) (Table 1). Healthy women were 8.9° more flexible than women with patellofemoral pain. Similar to the results comparing the symptomatic and asymptomatic knee, perceived pain was greater in women with PFPS due to pain experienced with the symptomatic knee.

The two groups produced similar force levels and the tape did not significantly influence force production ($F(1, 58) = 0.14$; $P> 0.1$) (Table 2). However, there was a significant angle effect on the amount of force produced ($F(8, 464) = 25.5$; $P< 0.01$). The greatest forces occurred at the 45° knee flexion angle and the lowest forces at 5° or close to full extension.

The overall activation of the VMO was higher for the PFPS group compared with the Healthy group ($F(1, 58) = 18.4$; $P< 0.01$); whereas the activation of the VL was not different between the two groups ($F(1, 58) = .18$; $P> 0.05$). As expected, the AEMG varied significantly with knee flexion angle for both vasti muscles (VMO: $F(8, 464) = 340.1$, VL: $F(8, 464) = 300$; $P< 0.01$). The most important finding was that the effect of taping varied as a function of knee angle differently for the two groups (VMO: $F(24, 1392) = 2.4$, VL: $F(24, 1392) = 2.1$; $P< 0.01$) (Figs. 4 and 5). When tape was applied to women with patellofemoral pain (PFPS), with the exception of the 85° angle, the activity of the VMO increased across all angles. In contrast, when tape was applied to the healthy women, the activity of the VMO decreased. For

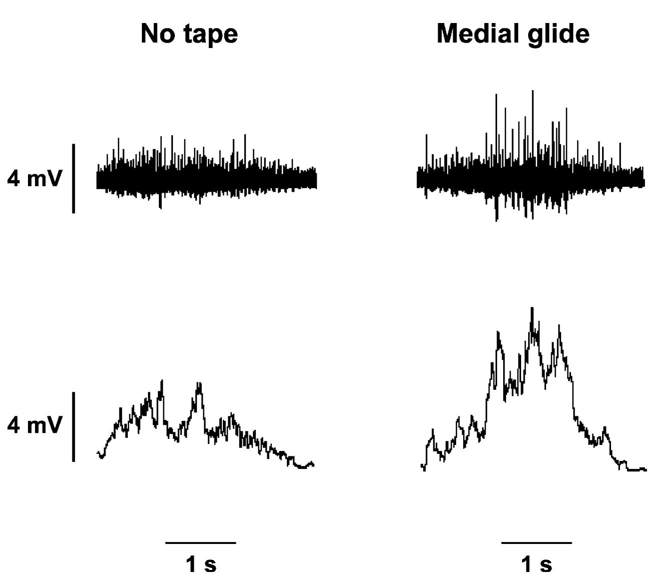


Fig. 4. Example of the effects of medial glide on VMO EMG. The top row represents the interference EMG during the two taping conditions from a subject suffering from PFPS, whereas the bottom row represents the averaged (time constant of 50 ms) and rectified EMG.

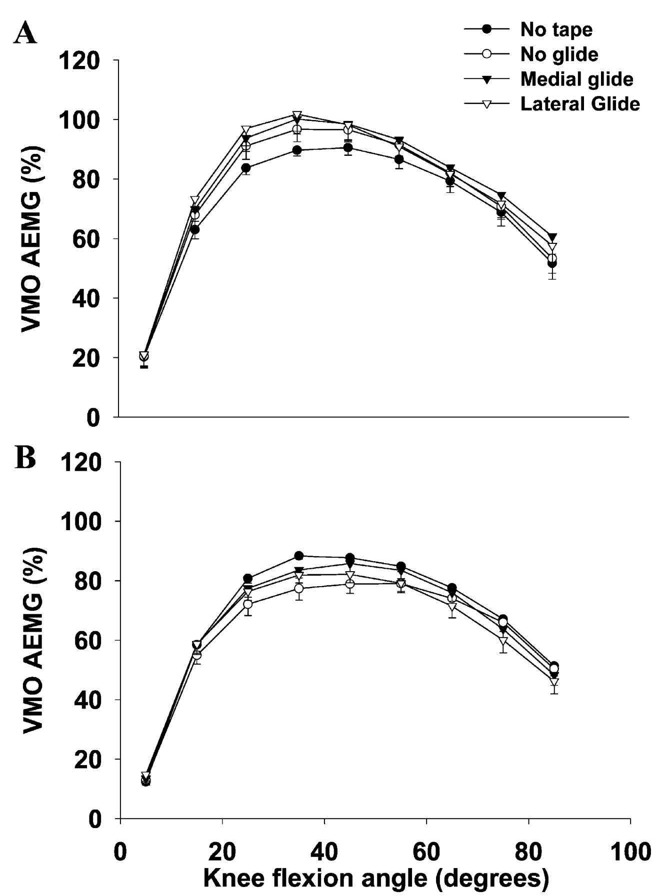


Fig. 5. The AEMG of the VMO for the control (no tape), placebo (no glide), and two experimental taping procedures (medial and lateral glide) as a function of knee flexion angle (0° is full extension) for the PFPS (A) and Healthy (B) groups. Any form of taping increased the VMO activity in the PFPS group, particularly at knee flexion angles ranging from 25° to 55°; whereas, taping decreased the VMO activity in the healthy group.

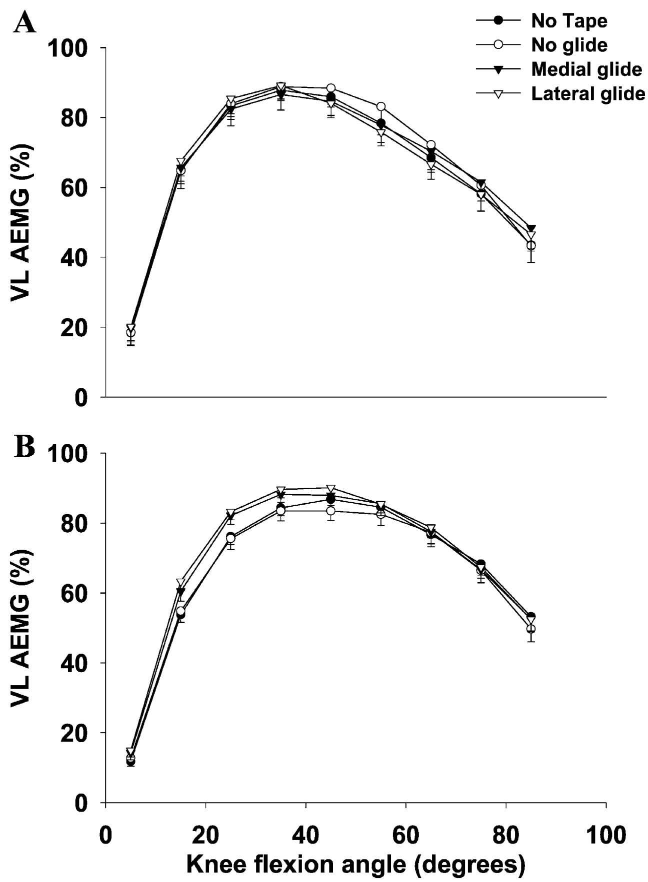


Fig. 6. The AEMG of the VL for the control (no tape), placebo (no glide), and two experimental taping procedures (medial and lateral glide) as a function of knee flexion angle (0° is full extension) for the PFPS (A) and Healthy (B) groups. Taping did not influence the VL activity in the PFPS group, whereas the two experimental procedures increased the VL activity in the healthy group, particularly at knee flexion angles ranging from 15° to 55°.

the PFPS group, all taping procedures consistently produced greater VMO activity in the range of 25–55°. For the healthy subjects, the no tape procedure had the highest VMO activity from 75° to 5° angles.

The activity of the VL with variation in knee flexion angle was influenced differently for healthy women and women with PFPS ($P < 0.01$) (Fig. 6). Taping the patella of women with PFPS had a non-significant effect on the activity of the VL during the first 50° of motion; however, between 45° and 25°, the medial and lateral glide decreased the activity of the VL compared with the no glide and control condition. In contrast, taping the patella of healthy women with a medial or lateral glide increased the activity of the VL from 5° to 45° of ROM. In the last 45° of ROM, however, the differences between taping procedures were non-significant ($P > 0.05$).

4. Discussion

The aim of this experiment was to investigate the effect of different patellar taping procedures on the activity of the VMO and VL muscles, force production, and perceived pain experienced by healthy women and women with current symptoms of PFPS. The results of the present study provided two original and clinically significant findings. First, patellar taping differentially effected the activity of the vasti muscles for healthy women and women with PFPS. Specifically, in women with PFPS, application of tape in any direction increased the activity of the VMO and decreased the activity of the VL. In contrast, in healthy women, the activity of the VMO decreased and the activity of the VL increased. Second, patellofemoral pain declined equally with the placebo and medial glide procedures, which indirectly (patellar position not measured) suggests that pain modulation with tape may not be due to changes in the patellar position.

4.1. Anthropometric measurements and force production

Several anthropometric characteristics, such as an increased Q-angle, tightness of the hamstrings, and internal rotation of the femur caused by an excessive pronation at the feet [31] can alter the position of the femur in relation to the tibia and eventually alter the tracking of the patella. Findings of this study suggest that only hamstring flexibility was different between healthy women and women with PFPS (healthy women were 8.9° more flexible). Hamstring tightness can alter tracking of the patella into the trochlea by externally rotating the shank and moving the tibial tuberosity laterally, which is the quadriceps tendon attachment. This will alter the Q-angle, which may be different during weight bearing and dynamic conditions (measured statically in this study). In addition, tightness of the hamstring can increase coactivation of the agonist and antagonist muscles crossing the knee joint during extension and alter motor performance [21].

Force production between healthy individuals and individuals with PFPS has been examined previously [19], however, no study has examined the effect of patellar taping on leg press force production. In contrast to knee extension movements, this laboratory task resembles multi-joint movements of daily life while velocity is controlled. Findings of this study indicated that there were no significant differences in force production between the asymptomatic and symptomatic knees or between the PFPS and Healthy groups. These findings support and extend previous results observed during knee extension movements [19]. Patellar taping procedures, furthermore, had no effect on the concentric force production, which is similar to previous findings during knee extension movements [34].

There are at least two explanations why force production did not differ between the Healthy and PFPS group and as to why force did not change with taping. First, the leg press is a multi-joint movement where several muscles in addition to the quadriceps muscles influence hip and knee extension. Taping the patella, which is a soft tissue joint in the dynamic chain of the lower extremity, may, therefore, have only a small influence on force production. Second, the major differences in force production between healthy individuals and individuals with PFPS were found during eccentric contractions of the quadriceps [3,19,34] and not during concentric contractions. Further studies are needed to identify whether force production is significantly influenced in patients with PFPS at faster concentric velocities and during weight bearing activities.

4.2. Patellar taping and activation of the vasti muscles

The VMO is the dynamic medial stabilizer of the patella and is considered functionally important in aligning the patella within the trochlea of the patellofemoral joint. Therefore, numerous studies have examined different exercises [10,18,20,23,24] and external means (tape or braces) [7,9,14,28,34] to decrease pain and increase the activity of the VMO in patients with PFPS. The findings of this study suggest that application of tape on the patella, independent of direction (including the placebo), decreased pain, increased the activity of the VMO, and decreased the activity of the VL in individuals suffering from PFPS. In contrast, patellar taping decreased the activity of the VMO and increased the activity of the VL in healthy individuals.

One possible explanation for the increased VMO and decreased VL activity with patellar taping in individuals suffering from PFPS is additional support to the medial ligaments of the patellofemoral joint. There is evidence that patients with PFPS compared with healthy individuals have greater injuries to medial ligaments around the knee joint [5]. The retinacula and the patellar ligament, two structures of the extensor mechanism, are important in balancing the patella to appropriately glide within the trochlear groove of the patellofemoral joint [4,5]. Injuries to the retinaculum or the medial structures of the knee will interrupt the connection between the patella and its guiding and controlling structures [4,5]. It is possible that patellar taping (especially with the medial glide) provided the needed mechanical support to the medial ligaments of the patellofemoral joint. Another possible explanation is that tape blocked the transmission of nociceptive information to the spinal cord via cutaneous stimulation [29]. For example, tape could have stimulated large sensory fibers at the skin (mostly on the medial side) and blocked the transmission of painful information from injured proprioceptors and ligaments in patients with PFPS [5]. Therefore, patellar taping decreased pain in women with PFPS either by supporting injured medial ligaments, by cutaneous stimulation, or by a combination of the two mechanisms. This reduction in pain, furthermore, could allow an individual suffering from PFPS to appropriately activate the VMO muscle and consequently achieve appropriate patellar tracking.

In contrast to the PFPS group, patellar taping decreased the VMO and increased the VL activation in healthy women. Healthy knees are believed to have the appropriate balance between the medial and lateral components (ligaments and muscles) that assist the patella to glide within the trochlear groove of the patellofemoral joint. If indeed patellar taping assists the medial components of the patellofemoral joint (e.g. ligamentous support), then the strategy utilized by the nervous system to activate the quadriceps muscles may be different for healthy compared with injured knees. Specifically, when a healthy knee is taped, the nervous system may lessen the activation of the VMO (medial dynamic component enhanced with tape) and increase the activation of the VL muscle (lateral dynamic component) to maintain the well-balanced gliding of the patella.

4.3. Direction of patellar taping and pain

The original proposition by McConnell [28] suggested that pulling the patella medially with tape decreased pain experienced by patients suffering from PFPS, increased VMO activity, and allowed them to perform functional exercises. Subsequent studies [6,7,9,14] supported the reduction in pain with the medial glide but failed to consistently show scientific evidence that patellar taping increases the VMO activity. Although the actual McConnell taping technique was not used in this study, our results partially support her hypothesis [28]. For example, we found that when pulling the patella medially with tape in women suffering from PFPS, patellofemoral pain decreased dramatically (86%) and the VMO activity increased significantly (~10–20%). Interestingly, all taping procedures including the lateral glide decreased patellofemoral pain (20–80%) and increased VMO activity (10–20%). The similar decreases in pain and increases in VMO activity between the placebo and medial glide taping procedure indirectly refute the proposition that taping alters patella position (actual patellar position was not measured in this study). This finding, furthermore, provides support to previous studies, which indicated that the reduction in patellofemoral pain was not associated with changes in patella position [6,25,36].

Independent of the underlying physiological mechanisms, the finding that partial (compared with McConnell's technique) patellar taping reduces pain up to 80% during multi-joint movements has tremendous clinical significance to the treatment of individuals suffering from PFPS. It provides novel scientific evidence that patellar taping will aid patients with PFPS to perform functional strengthening exercises of the quadriceps muscles. Furthermore, patellar taping increased the VMO activity in subjects with PFPS at knee flexion angles of 20–50°, which are commonly used during various forms of locomotion [1,17,33]. In addition to modulating pain, patellar taping would contribute to the rehabilitation of PFPS by increasing the activity of the VMO, the dynamic medial stabilizer of the patella, and thus improve the patellar gliding in the trochlear groove.

In summary, the present study demonstrated that during a multi-joint movement patellar taping decreased pain, increased the activity of the VMO muscle, and decreased the activity of the VL muscle in individuals suffering from PFPS. Although this finding supports McConnell's original hypothesis [29], because the experimental and placebo taping conditions increased VMO activity and decreased pain similarly, it indirectly refutes the proposition that functional knee improvements are due to a change in the patellar position. It is proposed that patellar taping, especially in a medial glide, may contribute positively to the rehabilitation of individuals suffering from PFPS possibly due to an enhanced support of the medial ligaments of the patellofemoral joint and/or by modulating pain via cutaneous stimulation.

Acknowledgements

The author would like to thank David Smith, M.D. and Melinda Flegel, M.S., A.T.C./L, for assisting with the diagnosis of women with PFPS. I would also like to thank Les Carlton, Ph.D., Carol MacGillis, P.T., and Thorsten Rudroff, Ph.D. for expert technical assistance and comments on a draft of the manuscript.

References

[1] A.M. Ahmed, C. McLean, In vitro measurement of the restraining role of the anterior cruciate ligament during walking and stair ascent, J. Biomech. Eng. 124 (6) (2002) 768–779.

[2] B. Arnold, D. Perrin, The reliability of four different methods of calculating quadriceps peak torque and angle specific torques at 30°, 60°, and 75°, J. Sport Rehab. 2 (4) (1993) 243–250.

[3] J.G. Bennett, W.T. Stauber, Evaluation and treatment of anterior knee pain using eccentric exercise, Med. Sci. Sports Exerc. 18 (5) (1986) 526–530.

[4] R. Biedert, P. Lobenhoffer, C. Lattermann, E. Stauffer, W. Muller, Free nerve endings in the medial and posteromedial capsuloligamentous complexes: occurrence and distribution, Knee Surg. Sports Traumatol. Arthrosc. 8 (2) (2000) 68–72.

[5] R.M. Biedert, E. Stauffer, N.F. Friederich, Occurrence of free nerve endings in the soft tissue of the knee joint. A histologic investigation, Am. J. Sports Med. 20 (4) (1992) 430–433.

[6] K. Bockrath, C. Wooden, T. Worrell, C.D. Ingersoll, J. Farr, Effects of patella taping on patella position and perceived pain, Med. Sci. Sports Exerc. 25 (9) (1993) 989–992.

[7] S.M. Cowan, K.L. Bennell, P.W. Hodges, Therapeutic patellar taping changes the timing of vasti muscle activation in people with patellofemoral pain syndrome, Clin. J. Sport Med. 12 (6) (2002) 339–347.

[8] K. Crossley, K. Bennell, S. Green, J. McConnell, A systematic review of physical interventions for patellofemoral pain syndrome, Clin. J. Sport Med. 11 (2) (2001) 103–110.

[9] K. Crossley, S.M. Cowan, K.L. Bennell, J. McConnell, Patellar taping: is clinical success supported by scientific evidence? Man. Ther. 5 (3) (2000) 142–150.

[10] W.D. Eisner, S.D. Bode, J. Nyland, D.N. Caborn, Electromyographic timing analysis of forward and backward cycling, Med. Sci. Sports Exerc. 31 (3) (1999) 449–455.

[11] A. Escalante, M.J. Lichtenstein, K. White, N. Rios, H.P. Hazuda, A method for scoring the pain map of the McGill Pain Questionnaire for use in epidemiologic studies, Aging (Milano) 7 (5) (1995) 358–366.

[12] S.A. Flaherty, Pain measurement tools for clinical practice and research, Aana J. 64 (2) (1996) 133–140.

[13] J.P. Fulkerson, Diagnosis and treatment of patients with patellofemoral pain, Am. J. Sports Med. 30 (3) (2002) 447–456.

[14] W. Gilleard, J. McConnell, D. Parsons, The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain, Phys. Ther. 78 (1) (1998) 25–32.

[15] J.C. Goh, P.Y. Lee, K. Bose, A cadaver study of the function of the oblique part of vastus medialis, J. Bone Joint Surg. Br. 77 (2) (1995) 225–231.

[16] M.D. Grabiner, T.J. Koh, L.F. Draganich, Neuromechanics of the patellofemoral joint, Med. Sci. Sports Exerc. 26 (1) (1994) 10–21.

[17] M.D. Grabiner, T.J. Koh, T.M. Lundin, D.W. Jahnigen, Kinematics of recovery from a stumble, J. Gerontol. 48 (3) (1993) M97–M102.

[18] W.P. Hanten, S.S. Schulthies, Exercise effect on electromyographic activity of the vastus medialis oblique and vastus lateralis muscles, Phys. Ther. 70 (9) (1990) 561–565.

[19] D.S. Hungerford, D.W. Lennox, Rehabilitation of the knee in disorders of the patellofemoral joint: relevant biomechanics, Orthop. Clin. North Am. 14 (2) (1983) 397–402.

[20] C.D. Ingersoll, K.L. Knight, Patellar location changes following EMG biofeedback or progressive resistive exercises, Med. Sci. Sports Exerc. 23 (10) (1991) 1122–1127.

[21] J.A. Isear Jr., J.C. Erickson, T.W. Worrell, EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat, Med. Sci. Sports Exerc. 29 (4) (1997) 532–539.

[22] P. Kannus, S. Niittymaki, Which factors predict outcome in the nonoperative treatment of patellofemoral pain syndrome? A prospective follow-up study, Med. Sci. Sports Exerc. 26 (3) (1994) 289–296.

[23] G.M. Karst, P.D. Jewett, Electromyographic analysis of exercises proposed for differential activation of medial and lateral quadriceps femoris muscle components, Phys. Ther. 73 (5) (1993) 286–295, (discussion 295–299).

[24] J. Laprade, E. Culham, B. Brouwer, Comparison of five isometric exercises in the recruitment of the vastus medialis oblique in persons with and without patellofemoral pain syndrome, J. Orthop. Sports Phys. Ther. 27 (3) (1998) 197–204.

[25] B. Larsen, E. Andreasen, A. Urfer, M.R. Mickelson, K.E. Newhouse, Patellar taping: a radiographic examination of the medial glide technique, Am. J. Sports Med. 23 (4) (1995) 465–471.

[26] D. Levine, A. Klein, M. Morrissey, Reliability of isokinetic concentric closed kinematic chain testing of the hip and knee extensors, Isok. Exerc. Sci. 1 (1991) 146–152.
[27] D.K. Lichota, Anterior knee pain: symptom or syndrome? Curr. Womens Health Rep. 3 (1) (2003) 81–86.
[28] J.S. McConnell, The management of chondromalacia patellae: a long term solution, Aus. J. Physiother. 32 (1986) 215–223.
[29] R. Melzac, P. Wall, Pain mechanisms: a new theory, Science 150 (150) (1965) 971–979.
[30] C.M. Powers, F.G. Shellock, T.V. Beering, D.E. Garrido, R.M. Molnar, T. Molnar, Effect of bracing on patellar kinematics in patients with patellofemoral joint pain, Med. Sci. Sports Exerc. 31 (12) (1999) 1714–1720.
[31] D. Reid, Anterior knee pain and the patellofemoral pain syndrome, in: D. Reid (Ed.), Sports Injury Assessment and Rehabilitation, Churchill, Livingstone, New York, 1992, pp. 345–398.
[32] S. Somes, T. Worell, B.C.D. Corey, Effects of patellar taping on patellar position in the open and closed kinetic chain: a preliminary study, J. Sport Rehab. 6 (6) (1997) 299–308.
[33] A. Vergis, J. Gillquist, Sagittal plane translation of the knee during stair walking. Comparison of healthy and anterior cruciate ligament-deficient subjects, Am. J. Sports Med. 26 (6) (1998) 841–846.
[34] S. Werner, E. Knutsson, E. Eriksson, Effect of taping the patella on concentric and eccentric torque and EMG of knee extensor and flexor muscles in patients with patellofemoral pain syndrome, Knee Surg. Sports Traumatol. Arthrosc. 1 (3–4) (1993) 169–177.
[35] D.L. Wieder, Patellofemoral tracking syndrome, Rehab. Manag. 6 (1) (1993) 99–102.
[36] T. Worell, C.D. Ingersoll, K. Bockrath-Pugliese, P. Minis, Effect of patellar taping and bracing on patellar position as determined by MRI in patients with patellofemoral pain, J. Athl. Train. 33 (1998) 16–20.

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