Influence of Infrapatellar and Suprapatellar Straps on Quadriceps Muscle Activity and Onset Timing During the Body-Weight Squat

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Abstract

Straub, RK and Cipriani, DJ. Influence of infrapatellar and suprapatellar straps on quadriceps muscle activity and onset timing during the body-weight squat. *J Strength Cond Res* 26(7): 1827–1837, 2012—The use of knee braces for the treatment of patellofemoral pain syndrome (PFPS) is widely documented, yet the mechanism by which such braces alleviate knee pain remains unclear. This study attempted to clarify this issue by simplifying the brace to the level of only straps. The effectiveness of an infrapatellar strap for PFPS remains controversial, and the use of a suprapatellar strap has not yet been documented. Quadriceps muscle activity and onset timing parameters were measured with surface electromyography (EMG) during a body-weight squat in 19 healthy subjects during 4 different knee-strapping conditions (infra, supra, both, and none). No differences in normalized mean or peak EMG activity in any part of the quadriceps were found. The onset timing of the vastus lateralis (VL) was significantly delayed when using an infrapatellar strap ($p < 0.05$) or both straps ($p < 0.05$) and marginally delayed when using a suprapatellar strap ($p < 0.10$) in comparison with the no-strap condition. No differences in the vastus medialis oblique (VMO) onset timing or VMO-VL onset timing difference were found among the strapping conditions, although an improvement in timing was noted with the suprapatellar condition. The results provide novel evidence that the application of an infrapatellar strap, suprapatellar strap, or both straps improves quadriceps muscle timing imbalances by delaying VL onset. Because the largest delay in VL onset occurred when wearing both straps, the combined application of an infrapatellar and suprapatellar strap may be the most beneficial in managing patellofemoral pain. Knee straps, unlike braces, are cost effective, nonrestrictive, and can be universally fitted to any knee and based on the results deserve further study in the patellofemoral pain population.

Key Words EMG, vastus medialis oblique, patellofemoral pain

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Introduction

Patellofemoral pain syndrome (PFPS) is used to describe pain-related problems occurring around the patellofemoral joint and accounts for 25–40% of all knee problems seen in sports medicine centers (12). Although the etiology of PFPS is unknown, the mechanism most commonly expressed as causing PFPS is abnormal patellar tracking, which can result in articular cartilage pathology (9,11,30). Maltracking of the patella can be caused by quadriceps muscle imbalances, specifically that of the vastus medialis oblique (VMO) in relation to the vastus lateralis (VL) (11,30) and occurs in about 50% of patients diagnosed with patellofemoral pain (8). In patients with PFPS, a delayed onset and decreased activation magnitude of the VMO in relation to the VL are frequently observed (7,11). Although a clinically relevant delay in VMO onset relative to the VL remains unknown (4), it has been suggested that a 5-millisecond delay in the VMO onset increases lateral patellofemoral joint loading (20).

Bolgla et al. performed a systematic review of the literature from 2000 to 2010 on PFPS and reported that current evidence supports the continued use of quadriceps strengthening, but the literature to support other interventions, particularly knee bracing, remains insufficient (2). The wide range of patellofemoral knee braces available makes it challenging in establishing a consensus for their use. Nevertheless, the use of knee braces for the treatment of PFPS has been widely documented, especially because many athletes have reported a benefit by wearing them (24). The proposed mechanisms of pain relief achieved through bracing include improving patellar tracking, dissipating lateral patellar forces, increasing patellofemoral contact area, altering patella alignment, increasing proprioception, and unloading the patellofemoral joint by decreasing quadriceps muscle activity (5).

To date, only one study has examined the inclusion of a knee strap in a patellofemoral brace. Hunter et al. compared the effect of a patellofemoral brace with and without a realigning strap, which is positioned to cup the lateral aspect of the patella to produce a medial force and found no differences in pain relief in persons with patellofemoral osteoarthritis (16). However, the influence of straps at other locations, particularly superior to the patella, has not been studied.

A suprapatellar strap compresses the quadriceps musculature and is sometimes found in knee braces to prevent brace migration (24). However, the location of the suprapatellar strap is likely important. A recent cadaveric study compared forearm muscle strain (using constant tension) when a tennis elbow strap was placed at distances of 80, 70, 60, 50, 40, 30, and 20% of the forearm length measured from the wrist (30). They found the effectiveness of the band varied with location, with the most effective location being on the muscle of the extensor carpi radialis brevis (i.e., 80% forearm length measured from wrist) rather than on the distal tendons. In light of these results, we speculated that a knee strap superior to the knee joint around the quadriceps (suprapatellar), specifically the VMO, would prove beneficial in the treatment of PFPS.

We theorized that because compressing the muscles of the forearm with a strap aids in the management of tennis elbow (12,17,21,22,26,29), one of the most common elbow problems in adults (6), a similar device at the quadriceps might aid in the treatment of PFPS. Although it is known that a possible mechanism behind the effectiveness of the elbow strap is to attenuate muscle activity (14,25), it is not known if a similar result is achievable with a comparable device (suprapatellar strap) at the knee.

The infrapatellar strap, a band worn just below the knee to compress the infrapatellar tendon, was introduced by Levine in 1978 to treat patellofemoral pain and is frequently used today for its management (19). Commonly used synonymous terms include Cho-pat strap, knee band, jumper's knee strap, and patellar tendon strap; the words strap, band, and brace are frequently used interchangeably. However, conflicting results have been reported in the literature in regard to the effectiveness of this device in alleviating pain (19,28).

To our knowledge, only 2 studies have examined the potential mechanism underlying the effectiveness of an infrapatellar device (1,18). A cadaveric study by Bohnsack et al. concluded that an infrapatellar brace alleviates patellofemoral pain by reducing patellofemoral contact pressure, contract area, and infrapatellar tissue pressure, and the benefits depend on the severity of cartilage damage–the more severe it is, the lesser the relief (1). A more recent study by Lavagnino et al. using radiographs concluded that an infrapatellar strap may limit excessive strain at the patellar tendon by decreasing the length of the tendon and by increasing the patella-patellar tendon angle (18). This study sought to add to these findings by determining if the infrapatellar strap could improve quadriceps muscle mechanics, specifically the timing and activity relationship between the VMO and VL.

Although potential benefits of an infrapatellar strap have been documented for the management of PFPS, it is not known whether the addition of a suprapatellar strap could provide further benefits. The application of infrapatellar and suprapatellar knee straps may improve the mechanics of the quadriceps and in turn minimize the need to wear knee braces, which (unlike straps) are often costly, restrictive, and not easily adjusted to any knee.

Therefore, the purpose of this study was to compare the influence of strapping (supra, infra, or both) to no strapping (control) on quadriceps muscle activity and onset timing using electromyography (EMG) in asymptomatic subjects. This is important, because muscle imbalances (i.e., a delayed onset and reduced activity of the VMO compared with the VL) predispose one to PFPS. Because of the lack of research in the area of knee straps, we chose healthy subjects first to determine if any changes would be detected with strapping before proceeding to an involved sample. We hypothesized that the application of knee straps during a squatting task would improve the timing and activity relationship of the VMO relative to VL. Specifically, we anticipated the following: (a) Both straps would result in the greatest improvement in the timing and activity relationship between the VMO and VL. (b) Either an infrapatellar or suprapatellar strap would improve the timing and activity relationship between the VMO and VL, but greater benefits would be seen with the suprapatellar strap. We anticipated more noticeable changes when using a suprapatellar strap based on the premise that a tennis elbow strap at the forearm is more effective when applied on the muscle belly than on the distal tendons.

Methods

Experimental Approach to the Problem

The mechanism of action by which patellofemoral braces alleviate knee pain remains unknown, yet improving patellar tracking has been suggested (5). Therefore, simplifying the brace to the level of only straps, which are often included to aid in patella stabilization, is warranted. Studies simplifying the brace to the level of only an infrapatellar strap report conflicting results in regard to pain relief (19,28), whereas studies simplifying the bracing to the level of only a suprapatellar strap are nonexistent. This study sought to examine if an infrapatellar and suprapatellar strap could provoke changes in quadriceps EMG activity and onset timing in subjects without patellofemoral pain and thereby potentially improve quadriceps muscle imbalances in those suffering from PFPS. Additionally, the information obtained will aid in quantifying patellar tracking dysfunctions in the patellofemoral population, because the recent literature has indicated a need for normative patellar tracking data (23).

The subjects were instructed to perform 10 repetitions of a body-weight squat under 4 different strapping conditions (infra, supra, both, and none) in a random order. Squat depth was consistent for all the subjects by using a chair as a marker, and squat stance was consistent between trials by placing a tape at each subject's preferred foot position. To standardize the activity and resistance across all the trials, only body weight was used.

Although muscle imbalances implicated in PFPS primarily include the VMO and VL (11,30), rectus femoris (RF) measurements were also obtained because this was the first study to explore the influence of strapping on muscle activity and timing parameters using EMG. The EMG signals of the recorded muscles were used to determine mean, peak, and onset timing variables. Mean EMG values were normalized to peak values to allow for comparison between subjects.

We used a repeated-measures design to compare strapping conditions separately for each of the muscle variables to answer the following research question: Does the activity and onset timing of the quadriceps during a body-weight squat differ within individuals across infrapatellar, suprapatellar, infra + suprapatellar (both), and no-strap (control) conditions?

Subjects

To participate, subjects were required to be (a) 18 to 45 years of age, (b) free of back of lower extremity pain, and (c) not pregnant. To be included in the study, the participants (a) should have been between 18 and 45 years of age, (b) should not have had current back or lower extremity pain, and (c) should not have been pregnant. The subjects were excluded from the study if they reported having (a) knee surgery or any knee injury in the previous 12 months, (b) physical therapy treatment for knee pain in the past 12 months, (c) history of patellar dislocation or subluxation, or (d) evidence of other knee or lower limb pathology (e.g., pain during squatting). A priori sample size estimate of 12 subjects was determined using G-Power 3.1 (University Kiel, Germany), based on a partial η^2 of 0.25 (from pilot work), and a power of 0.95.

The San Diego State University Institutional Review Board approved the study. All the subjects provided written informed consent before testing.

Electromyographic Measurements

All data were collected from the right leg using surface EMG during a single session. We did not select the dominant limb because a recent EMG study reported that muscle activity between the dominant and nondominant sides of the body during activities of daily living was symmetrical between limbs in healthy subjects (3). Surface electrodes (silver-silver chloride) were placed on the following muscle locations on the right limb: RF, VL, and VMO. The reference electrode was placed over the tibial tubercle. Before electrode placement, the skin was shaved and cleansed with alcohol. To ensure accurate electrode placement, the data were visually inspected during an isometric muscle set. Once properly positioned, leads were attached to the electrodes and connected to a wireless transmitter. All EMG apparatus (electrodes, leads, transmitter, receiver, and computer processing) used the Noraxon system (Noraxon USA, Scottsdale, AZ, USA).

After electrode placement, an electronic goniometer (Noraxon USA) was attached to the tested limb, with its center of rotation on the lateral surface of the knee, to measure the initiation of movement and range of motion at the knee joint. The goniometer was used to identify a single squat repetition, defined as the period that began and ended with the knee extended. The goniometer was time synched with the EMG to allow for the demarcation of each repetition. Digitally acquired data for all squat conditions were preamplified with a gain of 500, bandpass filtered between 20 and 500 Hz, sampled at 1,000 Hz, and converted to digital using a 12-bit A-D converter (Noraxon Telemyo 2400T, Noraxon USA).

Intervention

The subjects were tested under 4 separate conditions: no strap (control), infrapatellar strap, suprapatellar strap, and both straps all in 1 test session (Figure 1). For the strapping sessions, heavy-duty elastic neoprene straps (2.5″ × 18″ DynaWrap electrode strap, Dynatronics Corporation, Salt Lake City, UT, USA) were used.

We preferred this type of strap, opposed to a stiffer or narrower device, because it enables the tension to be more easily adjusted. Ng et al. compared various tensions in a tennis elbow strap (no brace, minimal tension, brace with 25-N tension, and brace with 50-N tension) in the subjects with lateral epicondylosis (21). They found that only the 50-N condition increased the tension required to produce pain with passive stretching of the wrist extensors. Even though we did not measure tension, based on the results of the aforementioned

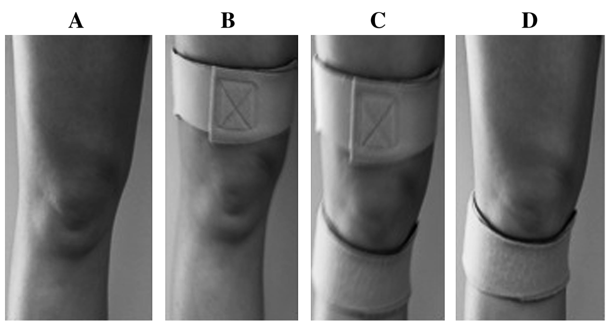

Figure 1. Bracing conditions: A) control; B) suprapatellar strap; C) both straps; and D) infrapatellar strap.

Figure 2. Body-weight squat.

elbow strap at the forearm is most effective in alleviating muscle strain when placed proximal to the joint susceptible to injury on the muscle belly (30).

The straps were tightened to fit snuggly and were carefully placed so that knee movement was not restricted or uncomfortable. The same investigator applied all the straps, and the order of the 4 conditions was randomized.

Procedures

Once the strapping conditions were secured, the subjects performed standing, body-weight squats while EMG was recorded for the muscle activity of the quadriceps muscles. The subjects were given the following instructions in regard to the squatting technique (Stellabotte, F and Straub, R. Stellabotte's way: The only personal trainer you'll ever need. Unpublished manuscript, 2010.): (a) Place feet shoulder width apart and rotate toes slightly outward (note, the tape was applied to the ground to ensure consistent foot placement among squatting trials). (b) Keep arms crossed in front of the body to maintain balance. (c) Descend until the back of your thighs tap the chair and then ascend. (d) Never allow your chin to pass in front of your knees to ensure proper back alignment. (e) Perform squats at a comfortable and constant rate.

The subjects were given a visual demonstration and allowed to practice until they felt comfortable. The subjects

study, we believe that the width and elasticity of the strap used in this study is superior for creating comfortable support with adequate tension.

Straps were wrapped circumferentially around the right knee with the subject seated and the knee flexed to 90°. The infrapatellar strap and suprapatellar straps were placed below and above the patella, respectively. The infrapatellar strap was placed around the patellar tendon as commonly prescribed (18,19,28), and the suprapatellar strap was placed superior to the knee around the VMO musculature. The position of the suprapatellar strap was based on the premise that a tennis

Table 1. Mean EMG activity of quadriceps (percentage of peak) during the dynamic squat with different strapping conditions.*†‡

	Strapping condition			
Muscle variable	Infrapatellar	Suprapatellar	Both	None
VMO (n = 19)	49.2 ± 9.1	50.6 ± 6.6	50.9 ± 7.2	51.8 ± 7.7
VL (n = 17)	50.6 ± 6.1	53.0 ± 6.3	51.4 ± 5.6	51.5 ± 6.1
VMO:VL ratio (n = 16)	94.1 ± 14.1	94.0 ± 11.0	98.5 ± 14.6	100.2 ± 14.6
RF (n = 18)	46.6 ± 6.9	48.1 ± 8.6	48.2 ± 7.0	47.1 ± 7.9
Overall (n = 16)	48.0 ± 5.5	50.0 ± 5.2	49.6 ± 4.3	49.5 ± 4.6

*VMO = vastus medialis obique; VL = vastus lateralis; RF = rectus femoris; Overall = VMO, VL, and RF.
†Values are expressed as mean ± *SD*.
‡No differences were found among the strapping conditions for any of the muscle variables.

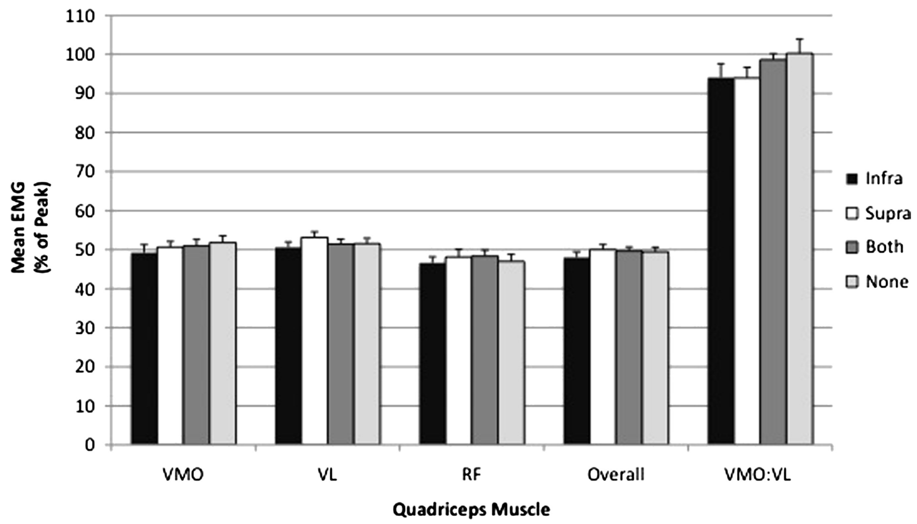

Figure 3. Mean electromyographic (EMG) activity of quadriceps during squat repetition with different strapping conditions. Signals are normalized to the peak EMG value obtained during the dynamic squat. Values are expressed as mean ± *SE*.

then completed 10 consecutive trials for data collection (Figure 2). The subjects were given a rest period of approximately 1 minute after the completion of each trial.

Electromyographic Analyses

The EMG activities of the VMO, VL, and RF were obtained during the squatting phase for 10 consecutive repetitions. All analyses consisted of approximately 8 repetitions; the beginning and ending repetitions were not used. Before analysis, data were full-wave rectified and smoothed using a root-mean square and a 100-millisecond window.

The mean EMG values for each muscle were normalized to peak values. Thus, the average muscle activity for each muscle is expressed as a percentage of its respective peak. In addition, the peak activity for each muscle was extracted for analyses. The mean EMG activity for each muscle was determined by averaging the mean EMG activities of the selected repetitions, and the peak EMG activity was determined by averaging the peak EMG values of the selected repetitions. The reliability of the mean EMG, using the intraclass correlation coefficient (model 1,3), ranged from 0.817 to 0.985 for the VMO, VL, and RF muscles.

The EMG onsets were calculated from the downward (eccentric) squatting phase using a computer algorithm that identified the point at which the EMG signal deviated by $>3SD$, for a minimum of 25 milliseconds, above the baseline

Table 2. Peak EMG activity of the quadriceps (microvolts) during the dynamic squat with different strapping conditions.*†‡

	Strapping condition			
Muscle variable	Infrapatellar	Suprapatellar	Both	None
VMO (*n* = 16)	150.5 ± 34.9	141.8 ± 22.2	137.5 ± 22.1	140.9 ± 28.0
VL (*n* = 15)	135.4 ± 28.6	133.6 ± 28.6	132.6 ± 26.2	133.8 ± 24.5
RF (*n* = 16)	93.0 ± 29.8	85.5 ± 29.3	83.5 ± 24.3	96.4 ± 43.9
Overall (*n* = 13)	129.5 ± 24.3	123.9 ± 23.5	121.5 ± 18.8	126.0 ± 28.5

*VMO = vastus medialis obique; VL = vastus lateralis; RF = rectus femoris.
†Values are expressed as mean ± *SD*.
‡No differences were found among the strapping conditions for any of the muscle variables.

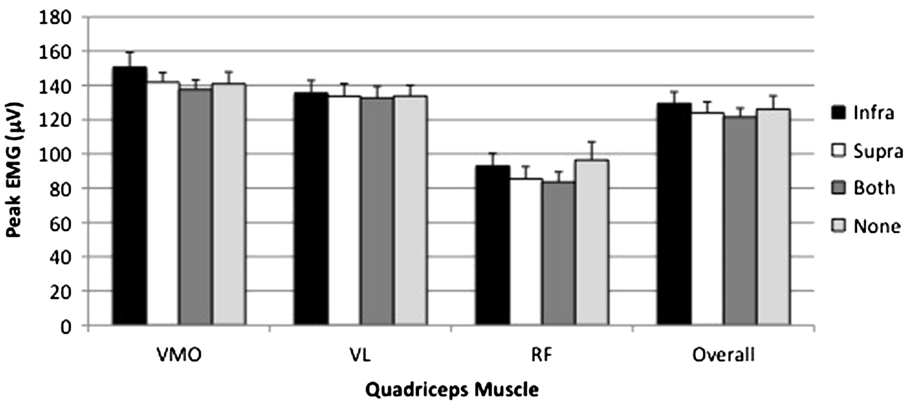

Figure 4. Peak electromyographic activity of quadriceps during squat repetition with different strapping conditions. Values are expressed as mean ± *SE*.

level (15). The EMG onsets identified by the computer were visually inspected to ensure the validity of the calculated values (15). The EMG onset for each muscle was determined by averaging the EMG onsets of the selected repetitions.

The onset timing of the VMO relative to VL was determined by subtracting the VL onset from the VMO onset (i.e., $\Delta = $ VMO-VL) (4). A negative value indicated an earlier VMO onset, whereas a positive value indicated an earlier VL onset. The reliability of the timing values ranged from 0.782 to 0.855 using the intraclass correlation coefficient (1,3) for each of the VMO and VL, respectively.

Statistical Analyses

All data were analyzed using SPSS Version 18 (Chicago, IL, USA). Scores were transformed to z-scores to detect outliers. Absolute z scores $\geq$2.0 were considered outliers and were excluded from the given analysis (e.g., comparison of normalized mean VMO activity across 4 strapping conditions). For subsequent analyses (e.g., comparison of peak VMO activity across 4 strapping conditions), all the scores were returned, and the above procedure was repeated. All analyses originally consisted of 19 subjects. After removal of outliers, the sample consisted of 13–19 subjects.

We first performed a 2 (sex) $\times$ 4 (strapping condition) mixed design multivariate analysis of variance (MANOVA) to address the issue of sex bias, as a result of the random sampling process, to determine if sex interacted as a factor. Second, we performed a one-way repeated-measures MANOVA in the absence of a significant interaction. Finally, we performed simple planned contrasts to compare the strapping conditions with the control condition (no strap) in the event of significant one-way repeated-measures MANOVA. This analysis protocol was conducted separately for each of the 13 dependent variables of interest: normalized mean EMG activity of the VMO, VL, RF,

Table 3. Onset timing of the quadriceps (milliseconds) during the dynamic squat with different strapping conditions.*†

	Strapping condition			
Muscle variable	Infrapatellar	Suprapatellar	Both	None
VMO ($n = 16$)	218.00 ± 83.13	185.63 ± 81.65	217.43 ± 74.04	225.40 ± 118.37
VL ($n = 17$)	244.15 ± 157.55	270.11 ± 207.99	285.34 ± 189.60	164.53 ± 99.68‡
RF ($n = 17$)	238.35 ± 88.44	218.36 ± 118.40	272.47 ± 132.56	214.35 ± 83.19
VMO-VL timing difference ($n = 13$)	14.42 ± 87.71	−90.85 ± 179.71§	−32.60 ± 176.13	79.57 ± 141.39

*VMO = vastus medialis obique; VL = vastus lateralis; RF = rectus femoris.
†Values are expressed as means ± *SD*.
‡Significantly earlier VL onset compared with both or infrapatellar strapping conditions ($p < 0.05$) and marginally earlier onset compared with the suprapatellar condition ($p < 0.10$).
§Not statistically significant from control but suggests a tendency toward an improved VMO-VL timing difference.

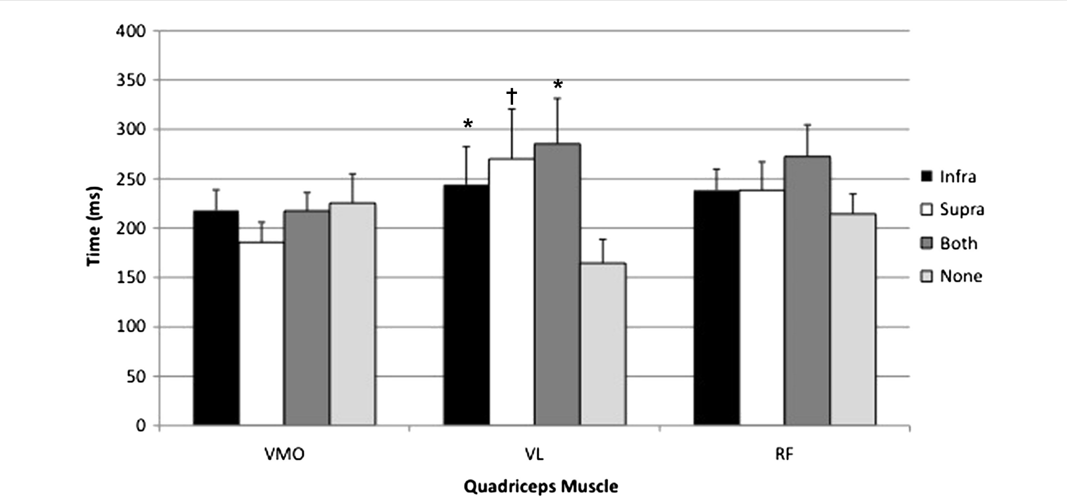

Figure 5. Electromyographic onset of quadriceps during the eccentric squatting phase with different strapping conditions. (*) Significantly delayed vastus lateralis (VL) onset compared with control ($p < 0.05$). (†) Marginally delayed VL onset compared with control ($p < 0.10$). Values are expressed as mean ± *SE*.

overall quadriceps, and VMO:VL ratio; peak EMG activity of the VMO, VL, RF, and overall quadriceps; and onset time of the VMO, VL, RF, and VMO-VL. The overall quadriceps value was calculated from the mean EMG activity of the VMO, VL, and RF.

Significance was established at $p \leq 0.05$. We also report on results with marginal significance ($p < 0.10$) to illustrate the potential use of strapping in the treatment of PFPS. A measure of effect size (partial eta-squared) is included for each one-way repeated-measures MANOVA.

Results

Results for all 2-way MANOVAs were not significant ($p > 0.05$). There was no sex × condition interaction effect, and therefore, all the results are based on the one-way MANOVAs.

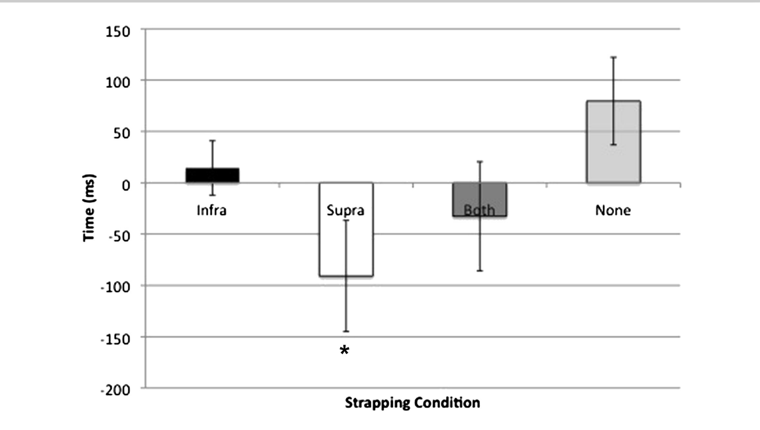

Figure 6. VMO-VL EMG onset timing difference during the eccentric squatting phase with different strapping conditions. Values >0 indicate that the EMG onset of the VL precedes VMO, and values <0 indicate that the onset of VMO precedes VL. (*) Not statistically significant from control but suggests a tendency toward an improved VMO-VL timing difference. Values are expressed as mean ± *SE*. VMO = vastus medialis obique; VL = vastus lateralis; EMG = electromyographic.

Normalized Mean Electromyographic Activity of Quadriceps

There were no differences among the 4 strapping conditions for the normalized mean EMG values of the VMO, VL, RF, VMO:VL ratio, or overall quadriceps ($p > 0.05$). The effect sizes for the VMO, VL, RF, overall quadriceps, and VMO:VL ratio are 0.22, 0.26, 0.16, 0.19, and 0.29, respectively (Table 1, Figure 3).

Peak Electromyographic Activity of Quadriceps

There were no differences among the 4 strapping conditions for the peak EMG values of the VMO, VL, or overall quadriceps ($p > 0.05$). Borderline differences in the peak EMG of the RF were found ($p < 0.10$); however, simple planned contrast revealed no differences between the control and other strapping conditions ($p > 0.10$). Effect sizes for the VMO, VL, RF, and overall quadriceps are 0.26, 0.03, 0.36, and 0.30, respectively (Table 2, Figure 4).

Electromyographic Onset Timing of Quadriceps during the Eccentric Squatting Phase

There were no differences among the strapping conditions for the onset timing of the VMO, RF, or VMO-VL onset timing difference ($p > 0.05$). Significant differences were found in the VL onset timing among the strapping conditions ($p < 0.05$). The onset timing of the VL when using no strap (mean ± *SD*, 165.53 ± 99.68 milliseconds) was significantly earlier than when using an infrapatellar strap (244.15 ± 157.55milliseconds; $p < 0.05$) or both straps (285.34 ± 189.60milliseconds; $p < 0.05$), and marginally earlier than when using a suprapatellar strap (270.11 ± 207.99 milliseconds; $p < 0.10$). Effect sizes for the VMO, VL, RF, and VMO-VL onset are 0.21, 0.48, 0.19, and 0.33, respectively (Table 3, Figures 5 and 6).

Discussion

The use of knee braces for the management of PFPS is common in sports medicine. A simplified knee brace would include only straps - infrapatellar, suprapatellar, or a combination of both. The purpose of such external support systems is to provide pain relief and to possibly alter muscle mechanics. This study investigated the role of individual and combined straps on quadriceps muscle activity. We used an asymptomatic population and a functional weight-bearing task to explore the effects of various strapping conditions on quadriceps EMG activity and onset timing.

One goal of this study was to examine the potential role of strapping on quadriceps onset timing. An imbalance in onset timing between the VMO and VL is associated with patellar lateral displacement, or maltracking, which overloads the patellofemoral joint and results in PFPS (13). It is proposed that individuals with PFPS have a delayed onset of the VMO compared with the VL, whereas healthy subjects have a simultaneous onset of the VMO and VL or an earlier onset of VMO (30). One of the most commonly used measures to assess the timing relationship between the VMO and VL is the VMO-VL onset timing difference (4). A positive or increasing onset timing difference is indicative of patellar maltracking and is often seen in conjunction with a delayed VMO onset or an early VL onset.

Our results failed to show any statistically significant differences in the VMO-VL onset timing difference between the 4 different strapping conditions. However, we used healthy subjects, without likely onset timing issues. Repeating this study with a symptomatic population, with proven onset timing issues, is warranted.

It should be noted, however, that the timing relationship between the VMO and VL was improved by all strapping conditions. Our subjects initially had an 80-millisecond delay in the VMO onset (Figure 6, Table 3). Wearing an infrastrap reduced the VMO delay to 14 milliseconds (82% decrease), adding a suprastrap eliminated the VMO delay (caused VMO to fire 33 milliseconds earlier, 141% decrease), and using solely a suprastrap was the most beneficial (caused VMO to fire 91 milliseconds earlier, 214% decrease). Although a clinically relevant VMO-VL timing difference has not been established (4), our results, although nonsignificant, may prove clinically relevant in a symptomatic population with a known timing dysfunction.

Comparing our findings with that of other studies is challenging, particularly because we are the first to evaluate the influence of knee strapping on muscle timing parameters. Nevertheless, our findings of large variations in VMO-VL in the control group (Table 3) are consistent with those of Pal et al. (23), who reported large ranges of VMO activation delays in an asymptomatic population (18 ± 57 milliseconds during walking and 28 ± 49 milliseconds during running). Similar ranges were seen in their PFPS group. The authors concluded that only a subset of the patellofemoral pain population has a tracking dysfunction (defined as having both abnormal patellar tilt and bisect offset values) that correlate with a VMO timing delay, and therefore, efforts to improve VMO timing will only benefit those with this specific tracking dysfunction. Consequently, large variations in timing data are expected when participants are not properly classified.

We found a significant delay in the VL onset when using an infrapatellar strap or both straps, and a marginal delay in VL onset when using only a suprapatellar strap, compared with the control condition (no strap). Specifically, on average, the VL fired at 165 milliseconds. Wearing an infrapatellar, suprapatellar, or both straps delayed VL firing by 244 milliseconds (48% increase), 270 milliseconds (64% increase), and 285 milliseconds (73% increase), respectively. Although the overall VMO-VL timing difference was not significantly altered, a slight delay in the VL onset might improve patellar tracking by minimizing timing imbalances (i.e., decrease the VMO-VL onset timing difference).

In regard to VMO onset, no differences were found among the strapping conditions. However, as can be seen in Figure 5, the supra condition yields a tendency toward an improved VMO onset (17% decrease), although not statistically significant. A trend toward an earlier VMO onset, in combination with a marginal delay in VL onset, may create a possible interaction sufficient to improve the VMO-VL onset timing difference (i.e., decrease the VMO-VL onset timing difference in comparison with the control condition), as can be seen in Figure 6. These changes are not statistically significant but point to a possible interaction. A larger sample size and a symptomatic sample of individuals should be considered in future studies.

Our results provide early evidence that the application of straps may improve quadriceps muscle timing imbalances by delaying VL onset. Because the use of both straps or solely an infrapatellar strap significantly delayed VL onset, with the largest delay occurring when using both straps, we speculate that the simultaneous use of an infrapatellar and suprapatellar strap may be the most beneficial in improving onset timing imbalances in the quadriceps. Because our subjects were asymptomatic without any reported history of PFPS, our conclusions must be interpreted with caution.

Another goal of this study was to examine the role of knee straps on quadriceps muscle activity. Earl et al. reported that healthy subjects using a Protonics knee brace (i.e., a long-leg brace that provides support above and below the knee) during a step-down exercise experienced less quadriceps muscle activity than when not braced (10). Earl et al. theorized that a reduction in muscle activity could alleviate knee pain by reducing the load on the patellofemoral joint. The results of our study failed to support this theory, because no differences were found in muscle activity between the control and any strapping condition. It should be noted that the Earl et al. study used a single leg body-weight squat (which they called a lateral step down), which most likely elicited a greater muscle contraction. Therefore, if we had used a more strenuous and less functional task, we may have obtained different results. Nevertheless, we conclude that a knee brace that provides support above and below the knee, as used in this study, does not alter quadriceps muscle activity during a functional task. However, whether such a device alters muscle activity during strenuous activity, which in turn may decrease the load on the patellofemoral joint and benefit those with patellofemoral pain, remains unknown.

The use of solely an infrapatellar strap in the management of PFPS, specifically in terms of pain, remains controversial because of inconclusive evidence in the literature (19,28). Our study failed to find altered muscle activity as a result of strap application below the knee. Thus, the benefit in using an infrapatellar strap is most likely explained by some other mechanism. One possible mechanism is based on a cadaveric study by Bohnsack et al., which concluded that an infrapatellar brace alleviates patellofemoral pain by reducing patellofemoral contact pressure, contact area, and infrapatellar tissue pressure, and the benefits depend on the severity of cartilage damage–the more severe it is, the lesser the relief (1). Another possible mechanism is based on a computational model using radiographic measurements by Lavagnino et al (18), which concluded that an infrapatellar strap decreases patella tendon strain by increasing the patella-patellar tendon angle and by decreasing the patellar tendon length.

To our knowledge, this is the first study to investigate the potential role of a suprapatellar strap in managing PFPS. Because compressing the forearm musculature with a strap may aid in alleviating tennis elbow by decreasing muscle activity (14,25), we speculated that such a device at the knee would aid in managing PFPS through a similar mechanism.

Contrary to our hypothesis, we found no significant differences in quadriceps muscle activity when using a suprapatellar compared with when not using a strap. One explanation for this finding may have been our use of healthy, rather than symptomatic subjects. Additionally, it is probable that our functional task (body-weight squat) was not of a high enough stress. Snyder et al. in an elbow study found that forearm strapping resulted in a significantly lower muscle activity in the forearm extensors (i.e., carpi radialis brevis and extensor digitorum communis) of healthy subjects during maximal isometric contraction (25). Therefore, if we had used a maximal isometric contraction, our results may have differed.

Assuming that a suprapatellar strap alleviates patellofemoral pain, we speculate the mechanism responsible is most likely one that has been theorized to occur at the elbow when using a forearm compression strap. Because our results failed to support the muscle attenuation theory, other possible mechanisms that may explain the potential benefit of compressing the quadriceps with a suprapatellar strap are as follows: (a) Strapping disperses the forces generated and thereby reduces painful inhibition, which in turn causes an increase in muscle strength (29). (b) Strapping reduces the forces at the tendo-osseous junction by supplying the quadriceps with an additional insertion to absorb forces (22).

However, because the effectiveness of a forearm strap remains inconclusive, despite its widespread use, we can conclude that continuing further study at the patellofemoral joint by using a pseudo strap (suprapatellar) may provide further insight into the use of compression at the forearm and in turn prove beneficial in the treatment of patellofemoral pain.

Our results provide early evidence that the application of an infrapatellar, suprapatellar, or both straps does not improve quadriceps muscle imbalances by altering muscle activity. However, because we used a healthy population during a functional and submaximal task, our results must be interpreted with caution.

A potential limitation of our study is that we examined muscle activity and timing parameters in healthy subjects with no evidence of knee pain. However, because this was the first study to investigate the influence of knee strapping using EMG, we felt a need to establish baseline data before proceeding to a symptomatic population. Nevertheless, our findings are not necessarily applicable to the patellofemoral population. Another limitation of our study is that we did not have subjects undergo a knee examination before testing. Therefore, the subjects that meet our exclusion criteria may have still had deficits that were not accounted for (e.g., patients undergoing 1-year postoperative treatment for anterior cruciate ligament injuries). As such, our results do not necessarily represent a pool of solely healthy subjects.

This study provides early insight into the use of individual and combined knee straps to alter quadriceps muscle activity and onset timing for potential management of PFPS, by evaluating their impact using EMG. In regard to muscle action, our findings were insufficient to support the use of straps to alter muscle activity. In regard to muscle onset timing, our results provide early evidence that the use of an infrapatellar strap, either alone or in combination with a suprapatellar strap, may improve quadriceps onset timing imbalances by delaying VL onset. Using only a suprapatellar strap, although only marginally delaying VL onset, may have a positive impact on the VMO-VL onset timing difference. The combined application of both straps may be ideal, but further research is needed, particularly in symptomatic subjects.

Practical Applications

The primary purpose of knee bracing for patellofemoral pain is to alleviate pain and improve patellar tracking. However, such braces are often restrictive, costly, and require custom fitting. Knee straps, on the other hand, are economical, nonrestrictive, and can be easily adjusted to any knee. The findings from this study indicate that knee strapping delays VL onset, which may in turn improve patellar tracking. Because the largest VL delay occurred when wearing both an infrapatellar and suprapatellar strap, we would suggest that the application of both straps, rather than a single strap, is best for the management of patellofemoral pain. However, because our results are based on a healthy population, further study is needed before any definitive conclusions can be made.

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References

1. Bohnsack, M, Halcour, A, Klages, P, Wilharm, A, Ostermeier, S, Ruhmann, O, and Hurschler, C. The influence of patellar bracing on patellar and knee load-distribution and kinematics: An experimental cadaver study. *Knee Surg Sports Traumatol Arthrosc* 16: 135–141, 2008.
2. Bolgla, LA and Boling, MC. An update for the conservative management of patellofemoral pain syndrome: A systematic review of the literature from 2000 to 2010. *Int J Sports Phys Ther* 6: 112–115, 2011.
3. Burnett, DR, Campbell-Kyureghyan, NH, Cerrito, PB, and Quesada, PM. Symmetry of ground reaction forces and muscle activity in asymptomatic subjects during walking, sit-to-stand, and stand-to-sit tasks. *J Electromyogr Kinesiol* 21: 610–615, 2011.
4. Chester, R, Smith, TO, Sweeting, D, Dixon, J, Wood, S, and Song, F. The relative timing of VMO and VL in the aetiology of anterior knee pain: a systematic review and meta-analysis. *BMC Musculoskelet Disord* 9: 64, 2008.
5. Chew, KTL, Lew, HL, Date, E, and Fredericson, M. Current evidence and clinical applications of therapeutic knee braces. *Am J Phys Med Rehabil* 86: 678–686, 2007.
6. Ciccotti, MG and Charlton, WPH. Epicondylitis in the athlete. *Clin Sports Med* 20: 77–93, 2001.
7. Cowan, SM, Bennell, KL, Hodges, PW, Crossley, KM, and McConnell, J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Arch Phys Med Rehabil* 82: 183–189, 2001.
8. DeHaven, KE and Lintner, DM. Athletic injuries: Comparison by age, sport, and gender. *Am J Sports Med* 14: 218–224, 1986.
9. Draper, CE, Besier, TF, Gold, GE, Fredericson, M, Fiene, A, Beaupre, GS, and Delp, SL. Is cartilage thickness different in young subjects with and without patellofemoral pain? *Osteoarthr Cartilage* 14: 931–937, 2006.
10. Earl, JE, Piazza, SJ, and Hertel, J. The protonics knee brace unloads the quadriceps muscles in healthy subjects. *J Athl Train* 39: 44–49, 2004.
11. Fagan, V and Delahunt, E. Patellofemoral pain syndrome: A review on the associated neuromuscular deficits and current treatment options. *Br J Sports Med* 42: 789–795, 2004.
12. Froimson, AI. Treatment of tennis elbow with forearm support band. *J Bone Joint Surg* 53A: 183–184, 1971.
13. Grabiner, MD, Koh, TJ, and Draganich, LF. Neuromechanics of the patellofemoral joint. *Med Sci Sports Exerc* 26: 10–21, 1994.
14. Groppel, JL and Nirschl, RP. A mechanical and electromyographic analysis of the effects of various joint counterforce braces on the tennis player. *Am J Sports Med* 14: 195–200, 1986.
15. Hodges, PW and Bui, BH. A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroenceph Clin Neurophysiol* 101: 511–519, 1996.
16. Hunter, DJ, Harvey, W, Gross, KD, Felson, D, McCree, P, Li, L, Hirko, K, Zhang, B, and Bennell, K. A randomized trial of patellofemoral bracing for treatment of patellofemoral osteoarthritis. *Osteoarthr Cartilage* 19: 792–800, 2011.
17. Jobe, FW and Ciccotti, MG. Lateral and medial epicondylitis of the elbow. *J Am Acad Orthop Surg* 2: 1–8, 1994.
18. Lavagnino, M, Arnoczky, SP, Dodds, J, and Elvin, N. Infrapatellar straps decrease patellar tendon strain at the site of the jumper's knee lesion: a computational analysis based on radiographic measurements. *Sports Health* 3: 296–302, 2011.
19. Levine, I. A new brace for chondromalacia patella and kindred conditions. *Am J Sports Med* 6: 137–140, 1978.
20. Neptune, RR, Wright, IC, and van den Bogert, AJ. The influence of orthotic devices and vastus medialis strength and timing on patellofemoral loads during running. *Clin Biomech* 15: 611–618, 2000.
21. Ng, GYF and Chan, HL. The immediate effects of tension of counterforce forearm brace on neuromuscular performance of wrist extensor muscles in subjects with lateral humeral epicondylosis. *J Orthop Sports Phys Ther* 34: 72–78, 2004.
22. Nirschl, RP. Tennis elbow. *Orthop Clin North Am* 4: 787–800, 1973.
23. Pal, S, Draper, CE, Fredericson, M, Gold, GE, Delp, SL, Beaupre, GS, and Besier, TH. Patellar maltracking correlates with vastus medialis activation delay in patellofemoral patients. *Am J Sports Med* 39: 590–598, 2011.
24. Paluska, SA and McKeag, DB. Knee braces: Current evidence and clinical recommendations for their use. *Am Fam Phys* 61: 411–418, 423–424, 2000.

25. Snyder-Mackler, L and Epler, M. Effect of standard and aircast tennis elbow band bands on integrated electromyography of forearm extensor musculature proximal to the bands. *Am J Sports Med* 17: 278–281, 1989.
26. Struijs, PA, Smidt, N, Arola, H, van Dijk, CN, Buchbinder, R, and Assendelft, WJJ. Orthotic devices for tennis elbow: A systematic review. *Br J Gen Pract* 51: 924–929, 2001.
27. Takasaki, H, Aoki, M, Oshiro, S, Izumi, T, Hidaka, E, Fujii, M, and Tatsumi, H. Strain reduction of the extensor carpi radialis brevis tendon proximal origin following the application of a forearm support band. *J Orthop Sports Phys Ther* 38: 257–261, 2008.
28. Villar, RN. Patellofemoral pain and the infrapatellar brace. A military view. *Am J Sports Med* 13: 313–315, 1985.
29. Wadsworth, CT, Nielsen, DH, Burns, LT, Krull, JD, and Thompson, CG. Effect of the counterforce armband on wrist extension and grip strength and pain in subjects with tennis elbow. *J Orthop Sports Phys Ther* 11: 192–197, 1989.
30. Wong, YM. Recording the vastii muscle onset timing as a diagnostic parameter for patellofemoral pain syndrome: Fact or fad? *Phys Ther Sport* 10: 71–74, 2009.