

The Effects of Patellar Taping on Knee Kinetics, Kinematics, and Vastus Lateralis Muscle Activity During Stair Ambulation in Individuals With Patellofemoral Pain

Gretchen B. Salsich, PT, PhD¹

Jacklyn H. Brechter, PT, PhD²

Daniel Farwell, DPT³

Christopher M. Powers, PT, PhD⁴

Study Design: Pre- and postintervention repeated measures design.

Objective: To determine the effects of patellar taping on knee kinetics, kinematics, and vastus lateralis muscle activity during stair ambulation in individuals with patellofemoral pain (PFP).

Background: Patellar taping is a common treatment technique for individuals with PFP. Specific data on whether patellar taping improves gait variables, however, are limited.

Methods and Measures: Ten subjects with a diagnosis of PFP were studied (five men, five women). The subjects' mean age, height, and mass were 36.5 ± 11.1 years, 173.1 ± 10.3 cm, and 70.9 ± 13.3 kg, respectively. Lower extremity kinematics, ground reaction forces, and vastus lateralis EMG were obtained simultaneously while subjects ascended and descended stairs, under taped and untaped conditions. Knee moments were calculated using inverse dynamics equations. Four 2×2 (tape condition \times stair condition) ANOVAs for repeated measures were generated for cadence and average stance phase knee extensor moment, knee flexion angle, and EMG.

Results: On the average, a 92.6% reduction in pain was observed following the application of tape. Increases in cadence, knee flexion angles, and knee extensor moments were observed under the taped condition for both stair ascent and descent; however, no difference in average vastus lateralis EMG was found.

Conclusions: Although patellar taping resulted in decreased pain and increased knee extensor moments, knee flexion angles, and cadence during stair ambulation, the vastus lateralis EMG activity level did not change with taping. Based on data from the vastus lateralis, care must be taken if improved gait parameters indicate change in muscle recruitment. *J Orthop Sports Phys Ther* 2002;32:3–10.

Key Words: biomechanics, gait, patella, physical therapy

Patellofemoral pain (PFP) is one of the most commonly treated orthopaedic conditions.^{5,18,21} PFP typically presents as retropatellar pain^{5,7,11,18,19} that increases during high demand activities such as stair climbing and squatting.^{5,11,18,19} The most widely accepted theory regarding the etiology of PFP suggests that symptoms are the result of excessive patellofemoral joint stress (force per unit area),^{11,12,27} owing to abnormal patellar tracking.^{7,14,22} Elevated patellofemoral stress, a result of excessive patellofemoral joint reaction forces or reduced patellofemoral contact area, or both, is believed to cause irritation and degradation of retropatellar tissues.^{11,17}

As the patellofemoral joint reaction force (PFJRF) increases with quadriceps muscle contraction and knee flexion angle,^{3,13,26} patients with PFP may adopt compensatory gait strategies to reduce pain and minimize PFJRF. For example, persons with PFP have been shown to demonstrate decreased stance phase knee flexion,^{6,20} decreased walking veloc-

¹ Assistant professor, Department of Physical Therapy, Saint Louis University, St. Louis, MO.

² Assistant professor, Department of Physical Therapy, Chapman University, Orange, CA.

³ Clinical instructor, Department of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA; Director, Body Rx Physical Therapy, Glendale, CA.

⁴ Director, Musculoskeletal Biomechanics Research Lab; Assistant professor, Department of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA.

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TABLE 1. Subject characteristics.

	Men (n = 5)			Women (n = 5)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	38.0	7.8	(27.0–46.0)	35.0	14.5	(22.0–55.0)
Mass (kg)	77.6	15.2	(59.0–97.1)	64.2	7.5	(57.2–76.7)
Height (cm)	178.9	10.7	(162.6–189.2)	167.3	6.2	(156.2–170.2)

ity,²⁵ and diminished vasti muscle activity²³ during level walking compared to individuals without PFP. In addition, Nadeau and colleagues²⁰ reported that subjects with PFP had reduced peak knee extensor moments compared to controls during level walking; however, this result was not statistically significant. The above-mentioned kinematic and kinetic compensations noted in individuals with PFP are suggestive of a quadriceps avoidance gait pattern, previously reported for those with an anterior cruciate ligament deficient knee.¹

A common treatment intervention for patients with PFP is patellar taping, a technique to correct patellar malalignment with specific tape application.¹⁹ It has been reported that patellar taping results in decreased pain,^{2,10,15,24} improved patellar alignment,¹⁶ increased quadriceps muscle activity,^{15,29} and increased quadriceps muscle torque production.^{15,29} In addition, Powers et al²⁴ have reported improved gait function following the application of patellar tape. Although these authors observed improved knee flexion during the loading response phase of level gait,²⁴ the effects of taping on kinetic variables were not explored.

To date, only one study has examined the effect of patellar taping on knee kinetics during a functional task. Ernst et al⁸ compared peak knee extensor moments and peak knee power under four conditions (no tape, involved knee; placebo tape, involved knee; McConnell¹⁹ tape, involved knee; no tape, uninvolved knee) and two tasks (step-down; vertical jump).⁸ These authors reported that subjects with PFP demonstrated an increase in peak knee moment and power during both activities with the McConnell taping technique compared to the three remaining conditions;⁸ however, no kinematic or electromyographic (EMG) data were reported in this study. Data regarding knee joint motion and quadriceps muscle activity could have helped substantiate the authors' claim that taping may have led to an increase in quadriceps muscle torque⁸ (ie, reversal of quadriceps avoidance).

Knowledge of the effect of taping on knee kinetics, kinematics, and EMG activity during stair ambulation in subjects with PFP would provide additional information about the usefulness of patellar taping as a treatment intervention for improving gait function. From a clinical standpoint, the high demand task of ascending and descending stairs often exag-

gerates compensation patterns in individuals with PFP, and as a result, step negotiation has become one of the primary diagnostic procedures used to establish the signs and symptoms of this condition.¹⁹

The purpose of this study was to determine the effects of patellar taping on knee joint kinetics, kinematics, and vastus lateralis EMG activity during stair ambulation in persons with PFP. We hypothesized that the application of patellar tape would result in increased knee extensor moments, knee flexion angles, and quadriceps EMG during stair ascent and descent in individuals with PFP.

METHODS

Subjects

Ten subjects (five men, five women) with a confirmed diagnosis of PFP participated in this study (Table 1). PFP was determined by the presence of retro patellar pain elicited by one of the following symptom provocation tests: resisted terminal knee extension, stair descent, or unilateral partial squat.¹⁹ Exclusion criteria were a history of knee ligament or cartilage injury, prior knee surgery, current pain originating from associated structures (plicae, bursae, patellar ligament), or neurological involvement that would influence coordination or balance during testing. Subjects were recruited from orthopaedic clinics in the greater Los Angeles area. Before participation, all subjects signed a consent form approved by the Institutional Review Board of the University of Southern California Health Sciences Campus.

Procedures

Before data collection, subjects were screened to determine if inclusion and exclusion criteria were met. Anthropometric measures (used for the calculation of lower extremity kinetics) were obtained with the subject in a barefoot, standing position. These measures consisted of bilateral leg length (distance from the center of the anterior superior iliac spine to the inferior aspect of the medial malleolus), knee width, and ankle width (measured with calipers), height, and body mass. In addition, all subjects completed a visual analog scale (VAS) to determine the level of pain in response to one of the symptom provocation tests described above. Briefly, the pain

scale consisted of a 100-mm horizontal line drawn on a piece of paper, such that the left edge of the line represented no pain and the right edge represented severe pain. Subjects were instructed to mark the line at the point corresponding to their pain levels. Chesworth and colleagues⁴ have shown the VAS to be a valid indicator of pain changes in individuals with PFP. It was not the purpose of this study to determine the effect of taping on pain, as this finding has been documented.^{2,10,15,24} Instead, pain assessment was necessary to determine whether taping procedures were performed with effectiveness.

To quantify quadriceps muscle activity, one bipolar surface electrode (preamplification = 300) (Motion Control, Salt Lake City, UT) was applied to the skin over the vastus lateralis (VL) muscle of the involved limb. The VL was chosen as it has been demonstrated that there is no difference in vasti EMG in persons with PFP during stair ambulation.²³ EMG obtained from the VL was representative of overall quadriceps function. The electrode was attached to an FM-FM telemetry unit (B&L Engineering, Los Angeles, CA), which was secured to the subject's waist with a strap. Differential amplifiers were used to reject the common noise (common mode rejection ratio = 60 dB), and the remaining raw EMG signal was amplified by 1000, band pass (20–500 Hz) and notch filtered (60 Hz), and sampled at 2400 Hz.

To quantify knee kinetics and kinematics during stair ambulation, three-dimensional motion analysis was performed using a six-camera, computer aided video motion analysis system (Oxford Metrics Ltd, Oxford, England). Kinematic data were sampled at 60 Hz and recorded digitally on a 166 MHz personal computer. Ground reaction forces were collected at a rate of 2400 Hz using a floor-embedded AMTI (Advanced Medical Technology, Inc, Watertown, MA) force platform.

A two-step wooden staircase (step height = 20.5 cm, tread = 27.5 cm, no hand rails) was positioned above the force platform, without contacting any portion of it, and one piece of floor tile was removed to allow access to the subfloor. With this arrangement, the force platform became one of three steps negotiated during ascent and descent (Figure 1).

Reflective markers (20-mm spheres) were placed directly on the skin of the subject's involved (painful) lower extremity according to Vicon protocol (Oxford Metrics Ltd, Oxford, England). Marker locations consisted of the right ASIS, left ASIS, sacrum, lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleolus, second metatarsal head, and calcaneus. The thigh and shank markers were attached to 2-inch wands that allowed inherent thigh and shank transverse plane rotation to be captured.

Subjects performed the first set of stair ascent and descent trials without tape to capture their natural compensation without the influence of any interven-

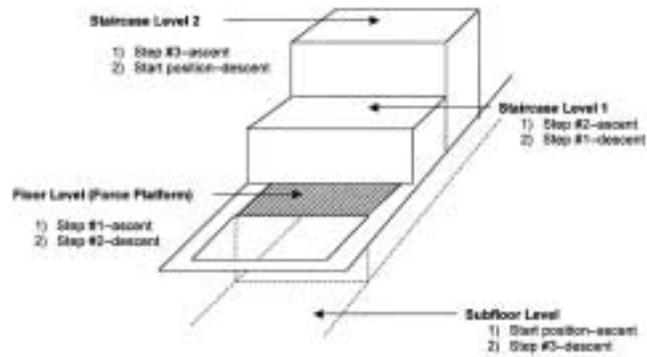


FIGURE 1. Stair configuration during data collection. Ascent: Subjects stood on subfloor (20.5 cm below force platform) before step initiation. Contact with the force platform was made with the involved lower extremity. Descent: Subjects stood on top step. Step initiation was made with the uninvolved lower extremity, allowing force plate contact with the involved limb.

tion. It was thought that if the taped trials were performed first, the untaped trials would not represent subjects' true gait patterns owing to a carryover effect. All subjects completed several practice trials to accommodate the stair apparatus and minimize the likelihood of an order effect. Participants were instructed to walk step over step at a self-selected pace. One trial was defined as one episode of ascent or descent. Two trials of stair ascent and descent were collected for all subjects with EMG, kinematic, and kinetic data obtained simultaneously. Three subjects reported an increase in pain following the untaped stair trials, which they indicated was more representative of their daily pain level than reported initially. Consequently, these subjects completed another VAS to indicate their pretape pain level, and the scores from their initial VAS were discarded. The remaining seven subjects did not report any changes in symptoms following the first set of trials, and their initial VAS scores were used in the analysis.

One investigator with 12 years experience in the taping technique described by McConnell¹⁹ applied patellar tape. Subjects were evaluated using McConnell's classification and taped according to instructions. The most frequently applied corrective tape procedures were medial glide and medial tilt. Tape application was determined to be successful if a 50% reduction in pain (quantified using the VAS) was achieved during the same symptom provocation test used to establish the pretape pain level.²⁴ If a 50% reduction in pain did not occur, the taping procedure was repeated until the desired decrease in pain was achieved. Typically, only 1–2 applications were necessary to achieve this criterion. Subjects completed several practice trials after the application of tape, and two trials of stair ascent and descent were obtained using the methods previously described.

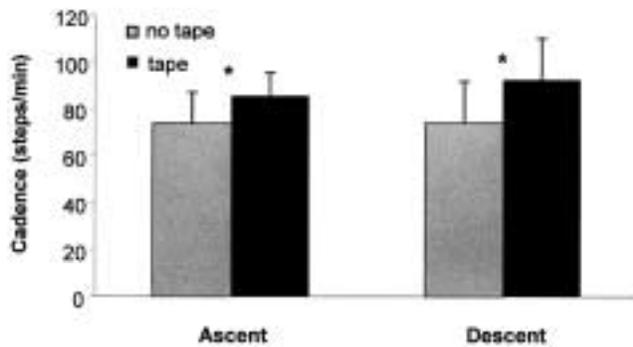


FIGURE 2. Cadence during stair ascent and descent for subjects with PFP ($n = 10$) under both taping conditions. Error bars indicate one standard deviation.
* Taping resulted in increased cadence during ascent and descent ($P = 0.02$).

Data Reduction

Using the VAS values from the pre- and posttape conditions, the percent difference in pain level was determined for each subject. As an indicator of walking speed, cadence (steps/min) was calculated during each trial of ascent and descent, and the average cadence computed for each stair/tape condition.

Utilizing a link-segment model and inverse dynamics equations (Oxford Metrics Ltd, Oxford, England), sagittal plane knee moment and angle curves were generated for each trial. All curves were expressed as a percentage of the stance phase, and knee moments were normalized to body mass. Raw EMG signals were full wave rectified and smoothed using a nonbiased linear envelope (100 ms). EMG data from nine subjects were used, as equipment malfunction led to erroneous signals for one subject. The two ascent trials and two descent trials for each tape condition were averaged for each subject, resulting in mean curves for the knee joint moment, knee angle, and VL EMG. As the symptoms of PFP are characteristically reproduced while weight bearing on the involved limb, the stance phase was relevant to the purpose of this study. Therefore, the knee angle, moment, and VL EMG amplitude were averaged over the entire stance phase.

Data Analysis

Analysis of variance (ANOVA) tests were performed using the following dependent variables: average knee extensor moment, average knee flexion angle, average VL EMG, and cadence. Each ANOVA was a repeated measures design consisting of two factors (tape condition and stair condition) with two levels in each factor (taped/untaped and ascent/descent). Only main effects for tape condition were reported, and if significant interactions were found, the main effects were analyzed separately using Student's t test (post hoc analysis). All analyses were performed using SPSS software (version 10.0), with significance levels set at $P < 0.05$.

RESULTS

Pain

On average, the pretape pain level was 5.4 ± 2.2 and posttape level was 0.4 ± 0.5 on a 10-point scale, resulting in a 92.6% reduction in pain.

Cadence

A significant tape effect for cadence was found with no associated interaction. On the average, subjects walked with a faster cadence during the taped trials compared to the untaped trials (stair ascent: 85.4 steps/min taped, 73.6 steps/min untaped; stair descent: 92.4 steps/min taped, 74.0 steps/min untaped). ($P = 0.02$) (Figure 2)

Knee Angles

When the average knee flexion angle was analyzed, there was a significant tape effect with no interaction. Subjects demonstrated greater knee flexion during the taped condition compared to the untaped condition during ascent (39.2° taped; 34.3° untaped) and descent (46.6° taped; 38.5° untaped). ($P < 0.001$) (Table 2, Figure 3)

TABLE 2. Average knee angles during stair ascent and descent for subjects with PFP ($n = 10$).

	No Tape			Tape			P^b
	Mean	SD	Range	Mean	SD	Range	
Ascent							
Average knee flexion angle ^a (deg)	34.3	4.5	(27.3–40.6)	39.2	5.8	(27.5–47.9)	< 0.001
Descent							
Average knee flexion angle ^a (deg)	38.5	5.6	(28.4–45.1)	46.6	5.6	(36.3–52.1)	< 0.001

^a Average knee flexion angle from 0–100% of stance phase.

^b F test for tape condition effect (ANOVA), $\alpha = 0.05$.

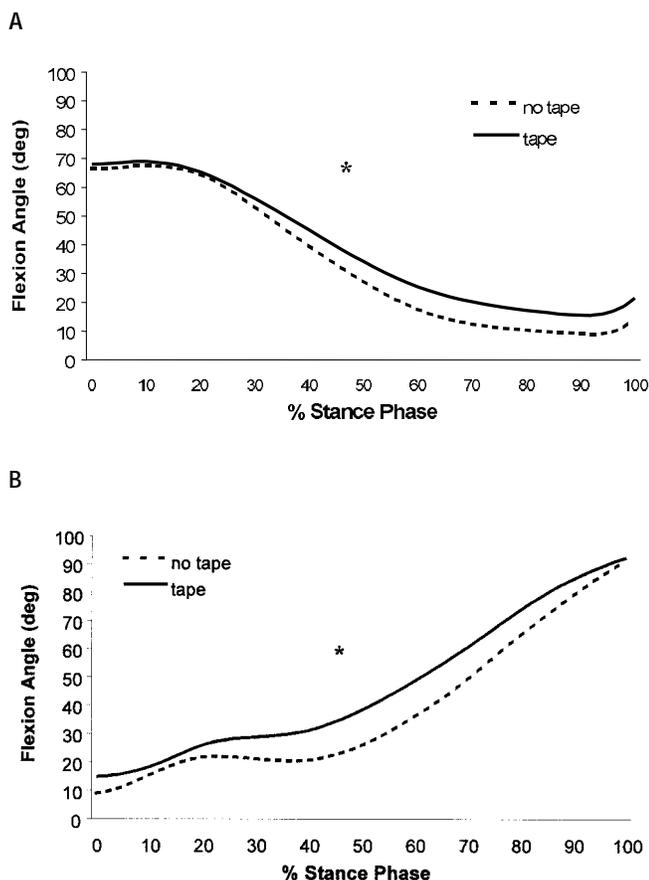


FIGURE 3. Knee angle ensemble averaged curves for stair ascent (A) and descent (B) ($n = 10$).

* Indicates average knee flexion angles from 0–100% of stance were significantly greater during the taped trials ($P < 0.001$).

Knee Moments

There was a significant tape effect with no interaction for average knee extensor moment, with subjects exhibiting greater values for the taped condition during stair ascent (0.30 Nm/kg taped; 0.12 Nm/kg untaped) and descent (0.55 Nm/kg taped; 0.37 Nm/kg untaped). ($P < 0.001$) (Table 3, Figure 4)

Vastus Lateralis EMG

Subjects did not demonstrate a change in VL EMG with the application of tape, as there was no effect

for tape condition and no interaction. Overall, subjects displayed similar EMG values for the taped and untaped conditions during stair ascent (1.16 mV taped; 1.26 mV untaped) and descent (1.24 mV taped; 1.32 mV untaped). (Figure 5)

DISCUSSION

Patellar taping resulted in an immediate reduction in pain (92.6%), similar to the findings reported by other investigators. Powers et al reported a 78% reduction in pain in individuals with PFP after taping,²⁴ while Bockrath² and Kowall¹⁵ indicated that pain was reduced by approximately 54 and 44%, respectively. The large reduction in pain achieved by the subjects in the current study corresponded with changes in gait characteristics including increased cadence, increased knee flexion angles, and increased knee extensor moments.

The finding of increased knee extensor moments is suggestive of increased quadriceps muscle torque generation. In addition, the combination of increased knee extensor moments and knee flexion angles suggests that subjects demonstrated an increased willingness to load the knee joint and accept greater patellofemoral joint reaction forces. The improved gait characteristics noted in this study are similar to the findings of Powers and colleagues,²⁴ who reported increases in knee flexion angle and walking velocity during level walking in response to taping, and Ernst et al,⁸ who noted an increase in peak knee extensor moment during a step up activity after the application of patellar tape.

One possible explanation for the increased knee extensor moments was increased cadence. Because stride length is relatively fixed during stair ambulation, cadence is an indicator of walking speed, which has been shown to influence moments during gait (either through increased segment accelerations or ground reaction forces).³⁰ Another factor that may have contributed to the changes in moment data obtained in our study was trunk posture. Although upper body kinematics were not assessed, observational analysis suggests that before taping, the subjects adopted a more forward trunk position during stair ambulation. This posture would move the trunk's center of mass anteriorly, creating a smaller external

TABLE 3. Average knee extensor moments during stair ascent and descent for subjects with PFP ($n = 10$).

	No Tape			Tape			P^b
	Mean	SD	Range	Mean	SD	Range	
Ascent							
Average knee moment ^a (Nm/kg)	0.12	0.17	(-0.13-0.35)	0.30	0.17	(-0.06-0.59)	< 0.001
Descent							
Average knee moment ^a (Nm/kg)	0.37	0.13	(0.15-0.58)	0.55	0.14	(0.37-0.87)	< 0.001

^a Average internal (extensor) moment from 0–100% stance phase.

^b F test for tape condition effect (ANOVA), $\alpha = 0.05$.

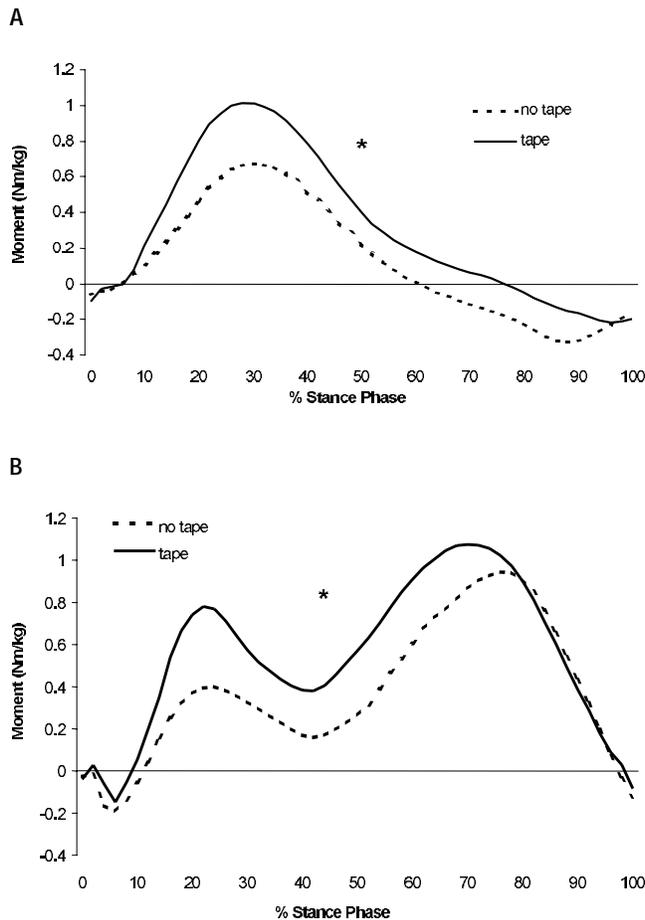


FIGURE 4. Knee moment ensemble average curves for stair ascent (A) and descent (B) ($n = 10$). Positive values = extensor; negative values = flexor. * Indicates average knee moments from 0–100% stance were significantly greater during the taped trials ($P < 0.001$).

knee flexion moment and corresponding internal knee extensor moment (ie, quadriceps avoidance). Taping appeared to result in subjects assuming a more upright posture, a position that would move the trunk's center of mass posteriorly, creating a greater external knee flexion moment and a corresponding increase in the internal knee extensor moment. Ernst and colleagues⁸ offered a similar explanation (altered trunk position) for their finding of increased knee moments after the application of tape.

The increased knee extensor moments obtained in the current study were associated with increased knee flexion angles during the same period of stance. This increase in knee flexion angle may have contributed to the increased external knee moment (and corresponding knee extensor moment) by moving the knee joint center more anteriorly with respect to the center of pressure.

The above-mentioned findings of increased knee extensor moments and increased knee flexion angles imply that subjects with PFP demonstrated a reversal

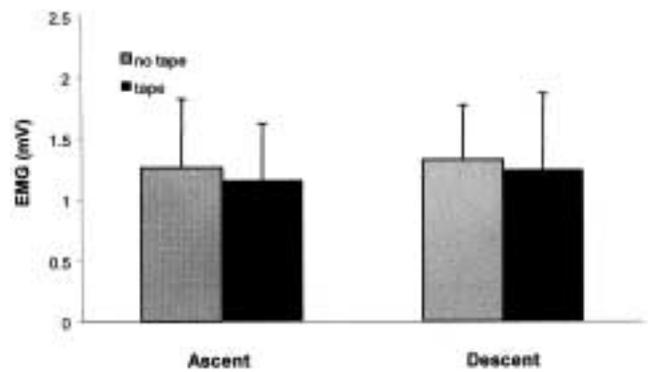


FIGURE 5. Vastus lateralis EMG (mV) for subjects with PFP ($n = 9$). EMG signals were averaged over the stance phase of stair ascent and descent. Error bars indicate one standard deviation. No differences were detected between taping conditions.

of the described quadriceps avoidance gait pattern after the application of tape. However, there was no corresponding increase in quadriceps muscle activity as measured by the VL EMG. This finding was unexpected and is difficult to explain. The lack of increased VL EMG may be related to two mechanical factors associated with the increased knee flexion angle. It has been reported that the lever arm for the quadriceps muscle group increases with knee flexion angle, reaching a maximum at approximately 45 degrees of knee flexion,²⁸ a value similar to the average knee flexion angle achieved during descent in the current study (taped condition). If the quadriceps lever arm was increased under the taped condition, an increased knee extensor moment may have been generated without an increase in quadriceps muscle force. Additionally, the increased knee flexion angle may have placed the VL muscle in a more optimal position for force generation due to improved length/tension characteristics. As a result, more quadriceps muscle force may have been generated at the same muscle activation level.

Another explanation for the discrepancy between the moment and EMG data may be related to the possibility that the application of patellar tape resulted in a different lower extremity muscle strategy to accomplish the task. A limitation of the inverse dynamics equations is that the calculated net joint moment is not specific to the exact muscles contributing to the moment. Although the net knee extensor moment increased significantly, other muscles that cross the knee joint and act on the femur or tibia segments may have contributed to the observed changes. Monitoring additional lower extremity muscles would determine the effect of taping on muscle activity patterns during stair ambulation. For example, evaluation of the entire knee extensor mechanism (all quadriceps muscles), hamstrings, and gastrocnemius would be necessary to understand compensatory mechanisms and treatment efficacy in individuals with PFP.

Clinical Implications

Several implications for rehabilitation are evident from the results of this study. Although patellar taping appears to be a useful treatment intervention for improving gait function in persons with PFP, the quadriceps muscle response to taping remains unclear. While patients appear to walk more normally with tape, the quadriceps muscles may not have responded to this intervention. Quadriceps muscle atrophy has been observed clinically⁹ in patients with PFP, and it is unlikely that a complete reversal of such a deficit would be evident in one testing session. It would appear that care must be taken to thoroughly evaluate each patient's quadriceps muscle performance status (eg, through isokinetic or functional performance testing), as improved gait parameters may not necessarily indicate improved muscular response. Clinicians should continue to emphasize muscle retraining as an important component of patellofemoral rehabilitation.

Limitations

While the present study appears to have clinical implications, several limitations need to be addressed. The sample size was notably small, ($n = 10$), and although it was sufficient to detect differences in several gait variables, care must be made in extrapolating these results to the entire population with PFP. It is possible that a true difference in VL EMG existed between the taping conditions but was not detected, given the large variability evident in our nine subjects (the observed power at $\alpha = 0.05$ was 0.21). However, a post hoc power analysis ($\alpha = 0.05$, power = 0.80) indicated that greater than 1200 subjects would be required to achieve a 6% difference in EMG. Even with a significant statistical effect, the clinical relevance of such a small difference in EMG amplitude is questionable.

Two additional limitations involve the EMG analysis used in this study. First, our methods may not have been sensitive enough to detect a difference in VL muscle activity. For example, averaging the EMG signal over the entire stance phase may have decreased the ability to detect differences that could have occurred during discrete periods. Second, only VL EMG was collected. It is possible that muscles other than the VL contribute to compensatory gait patterns in individuals with PFP, and, therefore, would respond to patellar taping more dramatically.

CONCLUSIONS

During stair ambulation, patellar taping resulted in decreased pain, increased cadence, increased knee flexion angles, and increased knee extensor moments in subjects with PFP. Despite these findings, VL EMG activity was not increased after taping, sug-

gesting that deficits in muscle recruitment or gait compensation still may have been present. Care must be taken to thoroughly evaluate the quadriceps muscle performance capability of individuals with PFP.

REFERENCES

- Berchuck M, Andriacchi TP, Bach BR, Reider B. Gait adaptations by patients who have a deficient anterior cruciate ligament. *J Bone Joint Surg Am.* 1990;72:871-877.
- Bockrath K, Wooden C, Worrell T, Ingersoll CD, Farr J. Effects of patella taping on patella position and perceived pain. *Med Sci Sports Exerc.* 1993;25:989-992.
- Buff HU, Jones LC, Hungerford DS. Experimental determination of forces transmitted through the patellofemoral joint. *J Biomech.* 1988;21:17-23.
- Chesworth BM, Culham EG, Tata GE, Peat M. Validation of outcome measures in patients with patellofemoral syndrome. *J Orthop Sports Phys Ther.* 1989;10:302-308.
- Devereaux MD, Lachmann SM. Patello-femoral arthralgia in athletes attending a Sports Injury Clinic. *Br J Sports Med.* 1984;18:18-21.
- Dillon PZ, Updyke WF, Allen WC. Gait analysis with reference to chondromalacia patellae. *J Orthop Sports Phys Ther.* 1983;5:127-131.
- Doucette SA, Child DD. The effect of open and closed chain exercise and knee joint position on patellar tracking in lateral patellar compression syndrome. *J Orthop Sports Phys Ther.* 1996;23:104-110.
- Ernst GP, Kawaguchi J, Saliba E. Effect of patellar taping on knee kinetics of patients with patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 1999;29:661-667.
- Fox TA. Dysplasia of the quadriceps mechanism: hypoplasia of the vastus medialis muscle as related to the hypermobile patella syndrome. *Surg Clin North Am.* 1975;55:199-226.
- Gilleard W, McConnell J, Parsons D. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Phys Ther.* 1998;78:25-32.
- Goodfellow J, Hungerford DS, Woods C. Patellofemoral joint mechanics and pathology. 2. Chondromalacia patellae. *J Bone Joint Surg Br.* 1976;58:291-299.
- Grana WA, Kriegshauser LA. Scientific basis of extensor mechanism disorders. *Clin Sports Med.* 1985;4:247-257.
- Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. *J Bone Joint Surg Am.* 1984;66:715-724.
- Insall J, Falvo KA, Wise DW. Chondromalacia patellae. A prospective study. *J Bone Joint Surg Am.* 1976;58:1-8.
- Kowall MG, Kolk G, Nuber GW, Cassisi JE, Stern SH. Patellar taping in the treatment of patellofemoral pain. A prospective randomized study. *Am J Sports Med.* 1996;24:61-66.
- Larsen B, Andreasen E, Urfer A, Mickelson MR, Newhouse KE. Patellar taping: a radiographic examination of the medial glide technique. *Am J Sports Med.* 1995;23:465-471.

17. Malek MM, Fanelli GC. Patellofemoral pain. An arthroscopic perspective. *Clin Sports Med.* 1991;10: 549-567.
18. Malek MM, Mangine RE. Patellofemoral pain syndromes: a comprehensive and conservative approach. *J Orthop Sports Phys Ther.* 1981;2:108-116.
19. McConnell J. The management of chondromalacia patellae: a long term solution. *Aust J Physiother.* 1986;32: 215-223.
20. Nadeau S, Gravel D, Hebert LF, Arsenault AB, Lepage Y. Gait study of patients with patellofemoral pain syndrome. *Gait Posture.* 1997;5:21-27.
21. Outerbridge RE, Dunlop JA. The problem of chondromalacia patellae. *Clin Orthop.* 1975;177-196.
22. Outerbridge RE. The etiology of chondromalacia patellae. *J Bone Joint Surg Br.* 1961;43:752-757.
23. Powers CM, Landel R, Perry J. Timing and intensity of vastus muscle activity during functional activities in subjects with and without patellofemoral pain. *Phys Ther.* 1996;76:946-955.
24. Powers CM, Landel R, Sosnick T, et al. The effects of patellar taping on stride characteristics and joint motion in subjects with patellofemoral pain. *J Orthop Sports Phys Ther.* 1997;26:286-291.
25. Powers CM, Perry J, Hsu A, Hislop HJ. Are patellofemoral pain and quadriceps femoris muscle torque associated with locomotor function? *Phys Ther.* 1997;77:1063-1075.
26. Reilly DT, Martens M. Experimental analysis of the quadriceps muscle force and patello-femoral joint reaction force for various activities. *Acta Orthop Scand.* 1972;43:126-137.
27. Seedhom BB, Takeda T, Tsubuku M, Wright V. Mechanical factors and patellofemoral osteoarthritis. *Ann Rheum Dis.* 1979;38:307-316.
28. Smidt GL. Biomechanical analysis of knee flexion and extension. *J Biomech.* 1973;6:79-92.
29. Werner S, Knutsson E, Eriksson E. 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.* 1993;1:169-177.
30. Winter DA. Kinematic and kinetic patterns in human gait: variability and compensating effects. *Hum Move Sci.* 1984;3:51-76.