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Review

The use of McConnell taping to correct abnormal biomechanics and muscle activation patterns in subjects with anterior knee pain: a systematic review

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Abstract. [Purpose] The aim of this review was to present the available evidence for the effect of McConnell taping on knee biomechanics in individuals with anterior knee pain. [Methods] The PubMed, Medline, Cinahl, SPORTDiscus, PEDro and ScienceDirect electronic databases were searched from inception until September 2014. Experimental research on knee biomechanical or EMG outcomes of McConnell taping compared with no tape or placebo tape were included. Two reviewers completed the searches, selected the full text articles, and assessed the risk of bias of eligible studies. Authors were contacted for missing data. [Results] Eight heterogeneous studies with a total sample of 220 were included in this review. All of the studies had a moderate to low risk of bias. Pooling of data was possible for three outcomes: average knee extensor moment, average VMO/VL ratio and average VMO-VL onset timing. None of these outcomes revealed significant differences. [Conclusion] The evidence is currently insufficient to justify routine use of the McConnell taping technique in the treatment of anterior knee pain. There is a need for more evidence on the aetiological pathways of anterior knee pain, level one evidence, and studies investigating other potential mechanisms of McConnell taping.

Key words: Patellofemoral pain syndrome, McConnell taping, Biomechanics

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INTRODUCTION

Anterior knee pain (AKP) is “a common symptom complex typically characterized by diffuse retropatellar or peripatellar knee pain exacerbated by activities that load the flexed knee joint”[1)]. Such activities include ascending or descending stairs, squatting, walking, running, or sitting for prolonged periods of time[2)]. Furthermore, AKP is a chronic condition, as the duration is typically more than three months and can continue to be a problem for years[3)]. Diagnosis of AKP is complex and can only be made when other pathologies such as intra-articular pathologies, patella tendinopathies, peripatellar bursitis, plica syndrome, Sinding-Larsen-Johansson syndrome, Osgood-Schlatter disease, and referred pain from the lumbar spine or hip have been ruled out[4, 5)].

Despite prolific literature, the aetiology of AKP remains unclear. However, it is suggested that the cause of AKP involves increased patellofemoral joint (PFJ) contact stress. This is mainly caused by knee flexion during dynamic weight-bearing activities[6)]. Factors influencing the load on the PFJ can be intrinsic or extrinsic. Extrinsic factors that might cause overload of the PFJ include increased training volume, an increase in speed, and increased training on stairs or hills. Factors such surfaces, footwear, and body mass or anthropometry might also need to be considered[7)]. Intrinsic factors could also influence the distribution of PFJ load. The distribution of load is conceptualized as movement of the patella within the femoral trochlear otherwise known as patellar tracking[8)]. It is proposed that individuals with AKP have lateral displacement of the patellar within the femoral trochlea[9)]. Intrinsic factors can be remote or local. Remote factors believed to influence patellar tracking include an increase in femoral rotation, increased valgus stress at the knee, increased tibial rotation, increased subtalar rotation, and inadequate flexibility. Local factors such as patella position, soft tissue contributions, and neuromuscular control of the vastii are hypothesized to contribute to abnormal tracking[7)]. These factors are frequently targeted with therapeutic interventions for AKP[10)].

The original taping intervention for treatment of AKP was developed by Jenny McConnell in 1986 in her landmark paper entitled “The Management of Chondromalacia Patellae: A Long Term Solution”[11)]. The rigid taping technique, also known as McConnell taping, is still frequently used in clinical practice[12)]. According to McConnell, there are four different components of malalignment that may need to be corrected: medial glide, medial tilt, anterior tilt and rotation.

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The choice of technique depends on how the patient presents and more than one component might need to be included[13]. According to McConnell, taping should provide immediate pain relief during functional activities such as squatting. If the pain is not reduced following taping, the method of taping used should be altered, and pain during functional activity should be reassessed. As the quadriceps are inhibited by pain, once pain relief is achieved, the individual should be able to perform pain free quadriceps exercises and functional activities (for example, squatting and stair climbing). Therefore, the combination of taping and exercise could also lead to strengthening of the quadriceps[11, 13]. However, the precise mechanism of patellar taping remains unclear. Reported expected effects could be due to neuromuscular, biomechanical, proprioceptive, or placebo mechanisms[14].

McConnell's taping theory argues that an active medial patella stabilizer, the vastus medialis oblique (VMO) muscle, could be activated through taping, thereby stabilizing the joint in opposition to the lateral pull of the remainder of the quadriceps muscle[11]. Another reported effect of patellar taping is repositioning of the patella within the femoral trochlea groove. This alters the PFJ contact load and joint reaction force, thereby reducing pain[15]. There is limited evidence suggesting that patellar taping alters the biomechanics in subjects with AKP. An MRI study done in 2004[16] found that taping induces medial glide of the patellar when the knee is in passive flexion. However, this may not be evident during functional activities in which individuals with AKP typically experience pain. Another study done in 2002[17] suggested that patellar taping increased knee flexion angles and knee extensor moments compared with no taping in an AKP population during stair ascent and descent. Due to conflicting evidence from EMG and insufficient evidence of patella biomechanics, some authors have proposed a proprioceptive somatosensory mechanism of taping[18].

A systematic review by Callagan and Selfe[19], questions the assumption that patellar taping results in immediate significant pain reduction. The review included five randomized controlled trials and described the effects of a McConnell taping intervention on pain, function, activities of daily living, and quality of life in individuals with AKP. A meta-analysis done on four of these studies for the Visual Analogue Scale (VAS) for pain showed no statistically or clinically significant difference between treatment with or without patellar taping. This suggests that the pain relieving effects of patellar taping might be overemphasised. Pooling of the other outcome data, that is, data concerning function, activity levels and quality of life, was not possible, as they were from individual studies and the results were conflicting.

Given the conflicting results of Callaghan and Selfe's review[19], we need to ascertain whether there is a biomechanical justification for the continued use of patellar taping techniques. Biomechanical abnormalities and muscular dysfunction are commonly reported as etiological pathways of AKP[20].The proposed underlying mechanism of the effect of taping involves its ability to "correct" abnormal knee biomechanics. Therefore, the effect of taping on biomechanics must be understood. Taping is an appealing intervention, as it is cost-effective and time efficient. It is also versatile and can be done in any environment and setting. If effective in the short and long term, it would be clinically useful. However, if it is not effective or has no scientific underlying rationale, it forces one to question why the technique, developed in 1986, is still routinely used today and advised for the treatment of AKP in current sports medicine[7, 21]. As there is a large body of literature on the topic, it would be useful to synthesize the evidence on the biomechanical outcomes of patellar taping, as they are proposed underlying mechanisms. This would serve to establish what has already been done, to address the limitations and recommendations of previous studies and to identify important gaps that will contribute to the field of knowledge.

Therefore, the aim of this review was to systematically appraise the evidence to determine if patellar taping results in an immediate change in tibiofemoral and patellofemoral kinematics and kinetics and lower extremity muscle activation (electromyography) in individuals with AKP.

METHODS

The study protocol was approved by the Health Research Ethics Committee of Stellenbosch University in Cape Town, South Africa. As this was a review of existing literature, informed consent from participants was not required. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

Randomized controlled trials (including cross-over randomized trials) and randomized single-subject experimental designs were eligible for inclusion. All other quantitative and qualitative research was excluded.

The review included studies on any individuals diagnosed with AKP, which could include any of the many synonyms associated with this condition (patellofemoral pain syndrome, patellofemoral joint dysfunction, retropatellar pain, patella malalignment syndrome, chondromalacia patella), as long as the studies conformed to the diagnostic criteria and excluded pathologies attributed to sources other than the PFJ. The studies included in this review needed to adhere to the diagnostic criteria most frequently used in previous systematic reviews[5, 22–24].

Based on these studies, the diagnostic criteria for the knee pain participants in the included studies were as follows: pain at the front of the knee or retropatellar pain that is aggravated by a functional activity that loads the flexed knee such as squatting, prolonged sitting, ascending or descending stairs, kneeling, lunging, or jumping. Males and females were included. Studies that included participants over the age of 40 were excluded in order to rule out osteoarthritis as a differential diagnosis. Studies that did not describe the diagnostic criteria used for the inclusion of participants were excluded.

Studies that described other disorders of the knee such as osteoarthritis, patella subluxation, or intra-articular pathology were excluded.

Studies investigating any type of McConnell taping intervention compared with a placebo or no taping were included. Studies using other taping methods such as K-tape were excluded. Studies using taping in combination with other interventions (multimodal treatment) were excluded. Studies investigating taping compared with another intervention were excluded. Multimodal treatment interventions that did not assess the effects of individual treatment strategies were excluded.

The primary outcomes of interest for this review were the biomechanical parameters of the lower extremity. We considered EMG studies with outcomes including but not limited to onset of muscle activation, average amplitudes, maximum amplitudes, and timing of onset and VMO/VL ratios. Fine wire and surface EMG studies were included.

Studies that used 3D motion analysis to acquire lower extremity joint kinematics were included. We included studies reporting on patellofemoral joint kinematics such as lateral, displacement, tilt, and rotation measurements, but tibiofemoral joint kinematics were also included in this review. Magnetic resonance imaging (MRI), computed tomography (CT) scan, and x-ray studies were excluded, since functional movement is not possible during these investigations.

Studies describing kinetic outcomes such as moments and ground reaction forces of the tibiofemoral joint or patellofemoral joint were included.

Studies investigating other outcome measures such as pain, function, proprioception, and strength measured without any biomechanical outcome measures were excluded. Outcomes measuring effects of taping immediately post intervention (short term) were considered. Outcomes measured during functional activities that commonly aggravate PFPS were considered. These activities included but were not limited to gait, stair climbing, running, squatting, and jumping.

A comprehensive search of published research reports in all accessible library databases was conducted at the Stellenbosch University Medical Library in September 2014. The following databases were searched for reports published up to June 2014: PubMed, EBSCOhost (MEDLINE, CINAHL, SPORTDiscuss), PEDro, Scopus, ScienceDirect. No date limit was applied to any of the databases. A number of key words were applied to each database's search tool to narrow the search and to develop the most precise strategy for the particular database. Only English articles were included. The same key search terms were used for all databases with the appropriate truncation and Boolean operators (such as AND and OR).

The key terms used for the search string were taping AND (anterior knee pain OR patellofemoral pain syndrome) AND (Kinematics OR kinematics OR electromyography) AND (effect* OR outcome* OR result*) AND (trial*). The same approach was used for all searches adapted as necessary according to specifics for that database. MeSH terms were used for "Anterior Knee Pain" in search engines, such as PubMed, that made use of that function. Pearling (checking the reference lists of identified studies) and hand searching (journals predating electronic databases or not appearing in electronic databases) were also conducted to increase the search base. Secondary searching was undertaken, when more detail of a study described in a systematic review was required, especially when articles within systematic reviews contained more detailed definitions for the various terms described. Google Scholar was also examined for any grey literature that was not represented within the databases.

A hierarchy of strength of evidence for treatment decisions:

- N of 1 trial
- Systematic reviews of randomized trials
- Single randomized trial
- Systematic review of observational studies addressing patient-important outcomes
- Single observational study addressing patient-important outcomes
- Physiologic studies (such as studies of blood pressure, cardiac output, exercise capacity, bone density)
- Unsystematic clinical observations

Fig. 1. McMaster hierarchy of evidence for intervention studies (McMaster University, 2014)

The searches were conducted by a researcher (DL) and an information specialist (WP) with experience in systematic review searches.

This review was done according to the PRISMA Guidelines. One reviewer (DL) screened the titles and abstracts of all initial hits and independently screened all potential full text papers according to the eligibility criteria described above. A second reviewer (QL) was consulted when necessary. The same two reviewers retrieved the full texts of all potentially relevant articles and then screened them independently using the same criteria in order to determine the eligibility of the papers for inclusion in the review.

The Cochrane Collaboration's tool for assessing risk of bias[25)] was used to assess the risk of bias of the included studies. A specific aspect of the study is targeted by individual entries in the tool, and a "risk of bias" table is generated within the tool that accounts for the judgement and support for the judgement for each entry. The risk of bias is recorded as "low", "high", or "unclear", the latter highlighting either lack of information or uncertainty with regard to the potential for bias. When the tool is used for clinical trials, as in the current study, biases are broadly categorized into five categories, that is, selection bias, performance bias, detection bias, attrition bias, and reporting bias, and other biases that do not fit into these categories. The reviewer referred to the user guidelines to assist in interpretation of the scale. Two randomly selected papers were reviewed by a second reviewer (SVN), and discrepancies in the results were discussed.

The Department of Medicine at McMaster University has developed guidelines for hierarchies of evidence that vary depending on which study design best answers a specific type of clinical question. These guidelines can be seen on their website[26)]. In this review, an intervention was investigated. Therefore, the evidence was graded according to the suggested McMaster guidelines for the hierarchy of evidence most appropriate for making treatment designs. The evidence levels are presented below (Fig. 1).

For this review, we considered Level 1 (single-subject designs) and Level III (single randomized trials). We established that there is no systematic review (Level II) that addressed this research question during a preliminary search.

A purpose-built MS Excel sheet was used for data management. A different sheet was used for each database, and

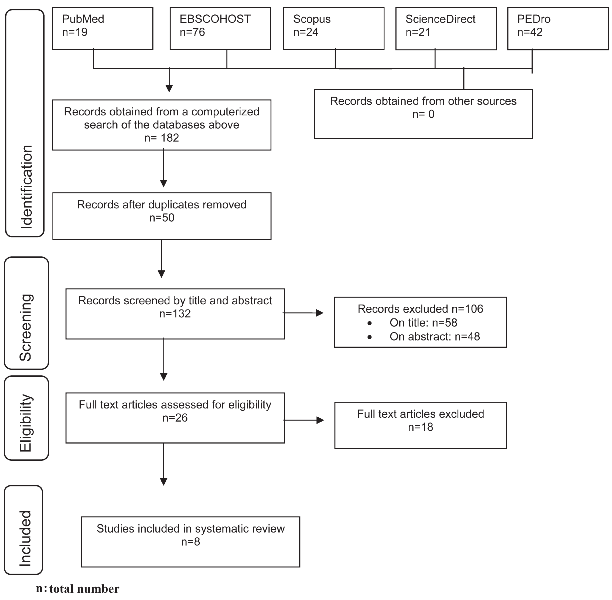

Fig. 2. Prisma guidelines for literature search

the information regarding search terms used, number of initial hits, number of studies excluded on title, number of duplicates, number of studies excluded on abstract, number of studies excluded on full text, number of included studies, references of included studies, and additional notes (including pearling) were entered into different columns.

Data from the included studies were then entered into another Excel spreadsheet based on the Cochrane data extraction form. Authors were contacted for missing trial data, methodology, and additional information as required. Data including author, title, year of publication, study design, sample size, methods and results in terms of mean differences (MD) and standard deviations (SD), 95% confidence intervals (CI), and p values were extracted from each included study and entered into purpose-built MS Excel sheets. The data for all outcomes, that is, kinematics, kinetics, and electromyography, were combined on one spreadsheet.

We extracted and analyzed the data of subjects with AKP only. For all eligible studies, the number of subjects with AKP, demographics, and pain characteristics were described narratively using tables or narrative summaries.

For the knee biomechanical outcomes, we extracted means and SDs of each outcome where available to allow effect size (ES) calculations. A random effects model in RevMan version 5.3 was used to calculate mean differences (as the measure of effect) and 95% confidence intervals. These values were presented as forest plots. A meta-analysis was conducted for knee biomechanical outcomes that more than one study evaluated and outcomes for the studies that were homogeneous.

We also extracted pain outcomes for studies that obtained aVAS) pain rating before and after the taping intervention.

RESULTS

The initial search based on the search words described above yielded a total of 182 hits. Following the application of the inclusion and exclusion criteria to the titles, 58 studies were excluded, and 50 duplicates were removed, reducing the total number of potential studies for inclusion to 110. The main reason for exclusion by title was that the studies were looking at conditions other than PFPS. After abstracts were read, 48 studies were excluded. The primary reasons for excluding these studies were the intervention used was not taping, the studies were not journal articles, and taping was done on asymptomatic participants. After reading the 26 full texts that were still eligible, the number of studies to be included in this systematic review was reduced to 8. The main reasons for excluding full texts included incorrect outcome measures and incorrect study design (not a randomized controlled trial). Results of the search strategy can be seen in Fig. 2.

The number of participants in each study varied from 14–40. The total sample was 220. In the eligible studies, 130 subjects had AKP, and the mean sample size was 27.5. Most of the studies included males and females. However one study included females only[27]. A sample description of the eight eligible studies can be seen in Table 1. The sample sizes, ages of participants, anthropometrics, and study settings appeared to be similar.

A common aim among all studies was to determine whether McConnell taping has an effect on a biomechanical outcome in subjects with AKP. However, there was significant heterogeneity amongst the studies included in this review. Four of the included studies investigated EMG, two studies looked at kinematics, and two studies looked at kinetics. Six of the studies had an asymptomatic control group, and two studies used a single group design. The study designs were all experimental, with the majority being randomized cross-over and repeated measures designs. The functional activities also varied, with step descent and single leg squatting being the most common activities tested. A description of the study aims as well as procedures can be seen in Table 2.

The Cochrane Collaboration's risk of bias scores revealed that studies that compared taping and no taping without a placebo taping intervention were judged as having an "unclear risk" for allocation concealment and blinding, as blinding is not possible in these situations. The studies that did not include a placebo taping invention were also judged as having a high risk of "other bias," as the risk of a placebo effect was high. Most of the studies were judged as having a "low risk" of attrition bias, as there were no dropouts. However, one study had missing outcome data[27]. One study[27] did not report any measures of variability for the kinematic outcomes.

Table 3 outlines the key diagnostic criteria used by the eligible studies to determine which participants were eligible to take part. Eligible studies used these criteria to determine study inclusion and exclusion criteria.

The biomechanical results that could not be pooled are summarized in Table 5. The table shows that there is conflicting evidence on the significance of biomechanical changes in the AKP population following taping. There is a large range of different EMG outcomes that have been investigated.

Table 1. Sample size and demographic information

	Sample size (n)			Gender (F/M)		Mean age (yr) (SD)		Mass (kg) (SD)		Height (m) (SD)		Study setting
	Total	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	
Mostamand, Javid et al.,2011	36	18	18	11M 7F	11m 7F	27.9 (6.3)	26.4 (4.9)	71.5 (9.5)	71.6 (11.1)	1.71 (0.06)	1.72 (0.08)	Motion Analysis Laboratory Queen Mary University of London, UK
Cowan, Sallie et al., 2002	22	10	12	3M 7F	4M 8F	22.7 (8)	19.5 (1.4)	59.3 (10.1)	60.8 (8.1)	1.67 (0.96)	1.7 (0.15)	Motion Analysis Laboratory University of Melbourne, Australia
Aminaka, Naoko; Gribble, Phillip, 2008	40	20	20	8M 12F	8M 12F	20.3 (1.87)	21.25 (2.67)	71.57 (14.04)	70.91 (11.41)	1.71 (0.12)	1.72 (0.876)	Motion Analysis Laboratory University of Toledo, Ohio, USA
Keet, Janet et al., 2007	35	15	20	4M 11F	7M 14F	29.1 (5.1)	29.4 (4.6)	65.2 (9.6)	64.4 (11.1)	DNR	DNR	Motion Analysis Laboratory Sport Science Institute, Cape Town, South Africa
Mostamand, Javid et al., 2010	36	18	18	11M 7F	11M 7F	27.9 (6.3)	26.4 (4.9)	71.5 (9.5)	71.6 (11.1)	1.71 (0.59)	1.72 (0.75)	Motion Analysis Laboratory Queen Mary University of London, UK
Ernst, G P et al., 1999	14	14	N/A	14F	N/A	24.4 (5.8)	N/A	66.5 (12)	N/A	1.73 (0.07)	N/A	Motion Analysis Laboratory University of Virginia, USA
Cowan, S M et al., 2006	22	10	12	DNR	DNR	23.0 (8.0)	19.5 (1.4)	59.3 (10.1)	60.8 (8.1)	1.67 (0.10)	1.71 (0.11)	Motion Analysis Laboratory University of Melbourne, Australia
Powers, C M et al., 1997	15	15	N/A	15F	N/A	26.5 (7.2)	N/A	65.1 (8)	N/A	1.64 (0.05)	N/A	Ranchos Los Amigos Patho-kinesiology Laboratory, Downey, California, USA

Table 2. Study information

Study	Study Aim	Design	Outcome of interest	Functional activity
Mostamand, Javid et al., 2011	To evaluate EMG activity of the vastus medialis and vastus lateralis following the application of patellar taping during a functional single leg squat.	Randomized crossover, 2 group	EMG Ratio of the VM: VL VL amplitudes, VM amplitude, VMO-VL onset (ms)	Single leg squat
Cowan, Sallie et al., 2002	To examine the effect of patellar taping on the onset of electromyographic activity of the vastus medialis obliquus relative to the vastus lateralis in participants with and without patellofemoral pain syndrome.	Randomized within subject.	Electromyographic onset of VMO and VL	Step descent
Aminaka, Naoko; Gribble, Phillip, 2008	To evaluate the effects of patellar taping on sagittal plane hip and knee kinematics, reach distance, and perceived pain level during the Star Excursion Balance Test in individuals with and without PFPS.	Repeated-measures design with 2 within-subjects factors and 1 between-subjects factors.	Sagittal-plane hip and knee kinematics	Single leg squat with reach
Keet, Janet et al., 2007	To examine whether patellar taping does decrease pain, increase quadriceps strength, and enhance neuromuscular recruitment.	Placebo-controlled clinical trial	EMG amplitudes VMO, VMO/VL ratio	Step descent
Mostamand, Javid et al., 2010	To measure sagittal plane knee moments and PFJRF after application of tape in patients with PFPS.	Randomized crossover, 2 group	Sagittal plane knee moments and PFJRF	Single leg squat
Ernst, G P et al., 1999	To examine the effect of McConnell patellar taping on single leg vertical jump height and knee extensor moment and power during a vertical jump and lateral step-up.	Single group, experimental repeated measures	Maximal knee extensor moment	Single leg vertical jumps and lateral step ups
Cowan, S M et al., 2006	To investigate the effect of patellar taping on the amplitude of electromyographic activity of vasti activation in subjects with and without patellofemoral pain.	Randomized crossover, 2 group	EMG amplitude of the VMO and VL	Ascending and descending stairs
Powers, C M et al., 1997	To assess the influence of patellar taping on gait characteristics and joint motion in subjects with patellofemoral pain.	Randomized crossover, 1 group	Sagittal plane knee kinematics	Gait, stair descent, ramp descent

Table 3. Diagnostic criteria for AKP

Key inclusion and exclusion criteria	Mostamand et al., 2011	Cowan et al., 2002	Aminaka et al., 2008	Keet et al., 2007	Mostamand et al., 2010	Ernst et al., 1999	Cowan et al., 2006	Powers et al., 1997
Clear definition of location of pain was reported	✓	✓	✓	✓	✓	✓	✓	✗
Age less than 40	✓	✓	✗	✗	✓	✗	✓	✗
Aggravated by the following:								
Prolonged sitting	✓	✓	✓	✓	✓	✗	✓	✓
Stair climbing	✓	✓	✓	✓	✓	✓	✓	✓
Squatting	✓	✓	✓	✓	✓	✓	✓	✓
Running	✓	✓	✓	✗	✓	✓	✓	✓
Kneeling	✓	✓	✓	✗	✓	✓	✓	✗
Hopping	✓	✓	✗	✗	✓	✗	✓	✗
Diagnosis was confirmed by a medical practitioner/ physiotherapist/trainer	✓	✓	✗	✗	✓	✗	✓	✗
No neurological involvement	✗	✗	✓	✗	✗	✗	✗	✗
No previous knee surgery	✓	✓	✓	✓	✓	✗	✓	✗
No internal derangement or other sources of lateral knee pain present	✓	✓	✓	✓	✓	✓	✓	✗
No previous spine or lower limb injury	✓	✓	✗	✓	✓	✓	✓	✗
Total number of inclusion/exclusion criteria present	12	12	9	7	12	7	12	7

Two studies[14, 27] investigated knee flexion angles; however, pooling of data was not possible, as the studies measured different outcomes. Aminaka & Gribble[14] measured the average peak knee flexion angle during a unilateral mini-squat, whereas Powers et al.[27] were interested in the knee flexion angle during loading response averaged across all testing conditions. Powers et al.[27], reported statistically significant results showing an increase in knee flexion with taping. Conversely, Aminaka and Gribble[14] yielded no statistically significant results for changes in knee flexion angles.

Pooling of data was possible for one kinetic outcome. Figure 3 illustrates the average knee extensor moments during loading response in PFPS subjects with or without tape. There was significant statistical heterogeneity amongst the studies. One of the studies yielded statistically significant results, however the overall effect was not statistically significant (MD, −0.09; 95% CI: −0.19, 0.01).

Other kinetic outcomes included the mean change in patellofemoral joint reaction force (PFJRF) and average coronal and transverse plane moments during the stance phase of stair descent[28]. PFJ contact force was significantly reduced during a single leg squat when tape was applied to the painful knee ($p=0.03$). The coronal and transverse plane moments demonstrated no change with the application of tape (Table 5).

Pooling of data was possible for two EMG outcomes. Figure 4 illustrates the average VMO/vastus lateralis (VL) ratio during the functional weight bearing activity in PFPS subjects with or without tape. There was no statistical heterogeneity amongst the studies. None of the individual studies yielded statistically significant results and therefore the overall effect was not statistically significant (MD, −0.10; 95% CI: −0.25, 0.06).

The meta-analysis for VMO-VL onset timing difference (Fig. 5) demonstrated statistically significant results in one study during both the concentric and eccentric phase of stair descent[29]. However, the overall effect was insignificant (MD, 24.48; 95% CI: −5.99, 54.94).

Other outcomes included percentage of maximum EMG activity of the VMO, average VMO amplitude, average VL amplitude, and percentage of change in EMG activity for the VMO and VL[29–32]. The percentage of maximum EMG activity of the VMO was significantly decreased with tape for both a stepping up task and stepping down task ($p<0.05$). None of the other outcomes were significantly altered with the application of tape (Table 5).

Table 5 shows the pain outcomes for the included studies. Three studies did not describe pain before and after taping. Of the five studies that included pain, four studies[14, 27, 29, 32] showed an immediate decrease in pain with taping and one study found no difference[31]. Three of the studies[29, 31, 32] that included pain had a placebo group, and all three found no difference in pain between no taping and placebo taping. Of the included studies, only two studies[27, 29] reported less pain and improved biomechanics, especially sagittal plane knee kinematics during gait[27], and improved VMO-VL onset timing during the eccentric phase of stair descent[29].

DISCUSSION

This is the first review aimed at assessing the evidence for the biomechanical effects of McConnell taping on the TFJ and PFJ in individuals with AKP. Eight small trials, including a total of 220 participants, 130 of which had a diagnosis of AKP, were included. Generally, the findings of this review indicate that McConnell taping does not alter knee kinematics and kinetics or muscle activation patterns

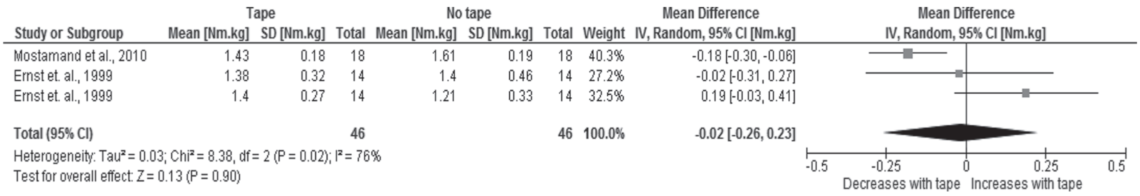

Fig. 3. Meta-analysis of average knee extensor moments during loading response in PFPS subjects

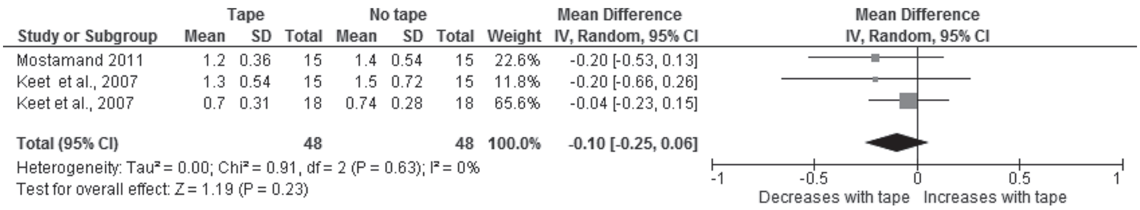

Fig. 4. Meta-analysis of average VMO/VL ratio during weight bearing activity in PFPS subjects

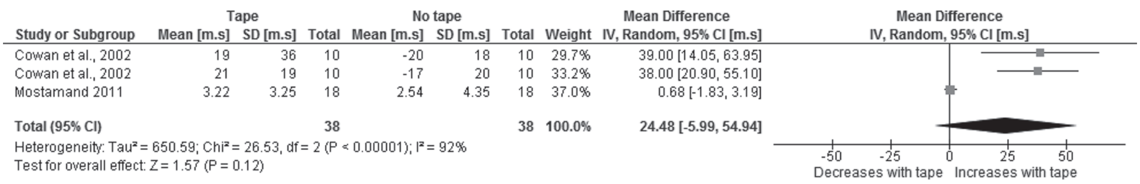

Fig. 5. Meta-analysis of average VMO-VL onset timing (m.s)

of the knee muscles.

This review found no significant changes in knee kinematics as a result of McConnell taping. One study[13] concluded that patellar taping might result in increased knee flexion angles during loading. Another study[27] supported this finding, however the effects were small, and it is still difficult to establish the causative mechanisms of this phenomenon. Conversely, Aminaka and Gribble[14] found no differences in peak knee flexion angles between taped and untaped conditions. Powers et al.[27] proposed that the loaded flexion angle increased as following an immediate decrease in pain with the application of tape. The decreased pain allowed the subjects to increase their knee flexion during weight-bearing activities. The results of this study should be interpreted with caution, as the study did not report on all outcomes and was missing measures of variability for the kinematic outcome data.

Selfe et al.[18] investigated the total range of movement of the TFJ with and without taping. The study revealed no significant changes in the sagittal or transverse plane. There was however, a significant decrease in the coronal plane ROM with taping, which could imply increased stability following taping.

Due to conflicting evidence, it is unclear whether McConnell taping has an effect on any kinematic outcomes.

It is proposed that patellar taping might increase knee extensor moments by improving quadriceps torques[17, 34, 35]. The evidence in our review does not demonstrate a significant effect on knee extensor moments to provide support for this theory. Pooled average knee extensor moment data (Fig. 4) from two trials showed no significant benefit from taping. In addition, the meta-analysis (Fig. 5) shows a large confidence interval for knee extensor moments, indicating an imprecise finding. This is clinically important, as taping is believed to improve the efficacy of knee extensor exercises[11]. If taping does not improve the knee extensor moments, it is unlikely that it will be useful in assisting quadriceps strengthening as McConnell (1986) originally proposed[11]. Therefore, clinicians should be cautious in prescribing these exercises in the presence of acute AKP.

Independently, one study[30] demonstrated a decreased patellofemoral joint contact force in the AKP group following taping. The authors estimated the PFJ contact stress through a process of biomechanical modelling using the net knee extensor moment to estimate the quadriceps force. The PFJ reaction force or contact force was then calculated as a product of the quadriceps force. The suggested reason for the decreased reaction force was an improved patellar position following the taping. The authors proposed that the improved position would improve the efficiency of the quadriceps moment arm, thereby decreasing the contact stress. More studies are needed to support these findings.

Pooled average VMO/VL ratio data from three trials showed no significant change with taping. In addition, the meta-analysis of VMO-VL onset timing data from three trials also demonstrated no significant benefit from taping. Separately, one trial[31] demonstrated favorable results after taping. In this trial, the percentage of maximum EMG activ-

Table 4. Biomechanical results of individual studies

Outcome	Study	Activity	Significant or not
VMO/ VL onset timing difference	Cowan et al., 2002	Concentric phase stair descent	Yes
	Cowan et al., 2002	Eccentric phase stair descent	Yes
% of max EMG activity of the VMO	Keet et al., 2007	Step up	Yes
	Keet et al., 2007	Step down	Yes
VMO amplitude	Mostamand et al., 2011	Single leg squat	No
VL amplitude	Mostamand et al., 2011	Single leg squat	No
VMO/VL onset timing difference	Mostamand et al., 2011	Single leg squat	Yes
% change in EMG activity of the VMO	Cowan et al., 2006	Stance phase stair ascent and descent	No
% change in EMG activity of the VL	Cowan et al., 2006	Stance phase stair ascent and descent	No
Change in PFJRF (N) with taping	Mostamand et al., 2010	Single leg squat	Yes
Average peak knee flexion (degrees)	Aminaka et al., 2008	Single leg squat	No
Average knee flexion across all conditions (degrees)	Powers et al., 1997	Stair ascent and descent Ramp ascent and descent Gait	Yes

ity of the VMO was significantly decreased with taping for both a stepping up task and stepping down task. This could indicate that the VMO muscle was working more effectively, however the clinical relevance is unclear. There is a lack of standardisation, for EMG outcomes in particular, making it difficult to compare the results.

The findings of the above study[31] are in agreement with a 2006 literature review synthesizing the literature on the effect of patellar taping in EMG studies[36]. The review found a lack of standardization in outcome measures. In addition, the results for altered muscle activation with taping are very conflict sharply with some showing altered activation and some showing no effect. This conflicting evidence may reflect the difficulty in measuring these outcomes and forces one to question the reliability of EMG measurements of muscle activation[37].

It is proposed that individuals with AKP present with a VMO/VL imbalance and a delayed onset of the VMO relative to the VL[38]. In 2004, an MRI study[39] found that AKP subjects had increased VMO activity and decreased VL activity post-taping. However, McConnell taping and placebo effects were similar, which underscores the need to include placebo taping in future research. The results of this review imply that McConnell taping is not sufficient to address VMO/VL imbalances in subjects with AKP.

Although it was not the primary objective of this study, we included pain outcomes in the results in order to determine if a change in biomechanics correlates to a change in pain. Four of the included studies[14, 27, 29, 32] showed that pain improved with taping, however, only two[27, 29] found a relationship between pain and biomechanics. This suggests that even if pain improves, biomechanics do not necessary change. This indicates that the mechanisms of McConnell taping are not necessarily biomechanical, as pain might improve as a result of other mechanisms, for example, proprioceptive or placebo effects. These aspects should be investigated in future research.

Overall, the clinical and statistical heterogeneity of studies was considerable, especially in terms of the outcome measures and functional activities investigated. All of the studies compared taping and no taping, however, four studies[29, 31–33] included a placebo taping as a control condition.

The McConnell taping approach was used in all of the studies, but the specific technique used varied. Four of the studies used the medial glide technique, which is the most commonly used technique for AKP. Four studies adjusted the technique according to the patella orientation, as described by McConnell in 1986. These corrective techniques included medial glide, medial tilt, anterior tilt, and rotation. The specific application procedures of the taping interventions such as the force of application, the type of tape used, and the number of layers of tape applied are also difficult to standardize.

All of the measured activities from the included studies were functional weight-bearing activities that commonly aggravate AKP, however the exact functional activities investigated varied amongst studies. The most commonly used activities were variations of the single leg squat[14, 28, 30] and stepping tasks or stair climbing[27, 29, 31, 32], but other activities including vertical jump, lateral step up, ramp ascent and descent, and gait were used. This makes it difficult to compare the studies, as the biomechanical requirements of the tasks are different.

One of the biggest challenges in the research of AKP is the variation and lack of consensus concerning definitions and diagnostic criteria for subjects. In this review, the table of diagnostic criteria, as shown in Table 4 , shows that there were similarities in how AKP was diagnosed, such as the functional activities used to reproduce symptoms and the exclusion of internal derangement. However, common areas of discrepancy were age and the exclusion of neurological involvement. These areas of inconsistency should be addressed in future research.

Only one study[30] focussed on the biomechanics of PFJ. One reason for this might be that it is difficult to assess the biomechanics of this joint with 3-Dimensional motion analysis and without the use of radiology, as it requires 3D modelling techniques. However, the measurement of PFJ

Table 5. Pain outcomes with taping for included studies

	Significant reduction in pain with McConnell taping compared with no taping	Biomechanical change post taping?	Description of biomechanical change
Cowan, Sallie et al., 2002	Yes, but pain values during step descent following taping intervention were not reported.	Yes	There was an improvement in onset timing of vastii with taping. VMO activation prior to VL activation with taping.
Aminaka, Naoko; Gribble, Phillip, 2008	Yes, the average pain decreased from 1.45 to 1.07 (p=0.005).	No differences in maximum hip and knee flexion angles	
Keet, Janet et al., 2007	No change in pain before and after taping. Pain values before and after taping not reported.	Yes	There was a significant decrease in the percentage of maximum VMO activity during the step up and step down tests.
Cowan, S M et al., 2006	Yes, but pain values during step descent following taping intervention were not reported.	No change in amplitude of VMO or VL activation or change in VMO/VL ratio	
Powers, C M et al., 1997	Yes, the average pain decreased from 7.7 to 1.7 with taping before activity.	Yes	There was a significant increase in loading response knee flexion during gait, stair ascent and descent, and ramp ascent and descent.

biomechanics before and after taping during functional weight-bearing tasks is a definite shortcoming in the literature. According to previous literature using radiographic methods including x-rays, CT scans, and MRI scans, the consensus is that taping does not change the alignment and position of the patella[16, 40, 41]. One study demonstrated a significant effect for inferior shift of the patella[42]. Pfeiffer et al.[16] concurred, stating that the beneficial effects of taping were related to factors other than patellofemoral alignment and that these other factors remain unknown.

In this review the review protocol was followed, and no changes were made. Full text articles that were not available through the University of Stellenbosch database were acquired through interlibrary loans. An effort was made to contact authors for missing data, and all of the authors responded. The results of the review were then adapted to include the missing data that met the inclusion criteria.

Two reviewers conducted the searches, reviewed full texts for inclusion or exclusion, and did the methodological appraisal independently. There were generally few discrepancies, and discrepancies that did occur were discussed. We can therefore conclude that the risk of bias in the process of this review was low.

All of the included studies had a low risk of selection and attribution bias.

For all of the included studies, the order of the testing conditions was randomized. However, only half of the studies[29, 30, 32, 33] described how the randomization was done. Therefore, we cannot determine if the procedures where truly random, and some selection bias might have occurred.

The risk of bias for the included studies was low for the majority of the outcomes. Future studies should include placebo taping and blind the allocation of the participants to a control or placebo group to reduce the risk of selection bias.

Only English papers were included in this review. This might have introduced language bias. Our review excluded studies using radiological methods. As a result, the evidence on PFJ biomechanics was limited. Our review cannot establish the mechanisms of biomechanical changes in the instances where they were significant results. These limitations should be addressed in future research.

The evidence is insufficient to draw conclusions on the biomechanical effects of taping. The current evidence does not validate the use of McConnell taping, as there were no other clinically or statistically significant findings. This deduction is in agreement with the review of Callaghan and Selfe[19] review and although the outcomes that they reviewed were different, the same overall conclusion, that there is insufficient evidence to support the efficacy of taping, was reported. However, both reviews investigated immediate effects only. As this review revealed that there is little evidence of the effect of taping on knee biomechanics during appropriate functional tasks that are commonly associated with AKP.

The findings of this review demonstrate that there is currently inadequate evidence for the effect of McConnell taping on biomechanics and muscle activation in individuals with AKP. This necessitates the questioning of the routine use of patellar taping in clinical practice. Given the multifactorial causes of AKP, McConnell's simplistic treatment approach might not be valid. However, one cannot rule out other potential mechanisms of effect such as proprioceptive mechanisms, which should be addressed in future research. Moreover, prospective Level I evidence is needed to investigate the efficacy of McConnell taping. Further research of the patellofemoral joint during functional weight-bearing activities is required.

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