Journal of Orthopaedics Spine and Sports Medicine

BIBLIOTICS JOURNALS
Orthop Spine Sports Med (2017)
1:1 003

Research Article

Maintenance of exercise-induced changes in the architecture of the VMO: how much is enough? An *in-vivo* ultrasound study

Running title: Maintaining exercise-induced VMO changes: how much is enough?

Harry Arnantha[1†], Claire Robertson[2†], Alban Killingback[3†], Philip J Adds[1*]

[1]Institute of Medical and Biomedical Education (Anatomy), St. George's, University of London, London, UK

[2]Wimbledon Clinics, Wimbledon, London, UK

[3]Department of Medical Physics and Clinical Engineering, St George's Healthcare NHS Trust, London, UK

(†) Equally contributed authors.

Abstract

Background: First-line treatment of patellofemoral pain usually involves exercises targeting the vastus medialis oblique. Previous studies have shown changes in muscle architecture after physiotherapy. However, there has been little research on long-term effects following cessation of therapy. The aim of this study therefore, was to determine the minimum amount of exercise required to maintain changes in the vastus medialis oblique achieved after six weeks of physiotherapy.

Methods: Sixteen healthy volunteers underwent an ultrasound scan to establish their initial vastus medialis oblique muscle fibre angle and insertion level. After a six-week exercise programme (phase 1), they were re-scanned. Participants were then randomly allocated to one of four groups to continue the exercises: once a week, twice a week, three times a week, or not at all, for a further 6 weeks (phase 2) after which they were scanned again.

Results: Phase 1: there was an average increase in fibre angle of 4.41° ($p<0.5$)

Phase 2: there was a mean decrease in fibre angle of 5.88° with no exercise, and 2.5° with exercises once a week; a gain of 0.75° with exercises twice a week, and a gain of 3.12° with exercises 3 times a week. There was a strong correlation between the change in insertion angle and ratio, and the number of knee exercises per week. There were no statistically significant changes in the insertion level of the VMO, either in phase 1 or phase 2.

Conclusions: The exercise programmes prescribed for patellofemoral pain have a positive effect on the vastus medialis oblique fibre angle and insertion level. However, it is necessary to continue exercises twice a week in order to maintain the gains achieved by the initial exercise regime.

Keywords: Vastus medialis; Exercise therapy; Patellofemoral pain syndrome; Ultrasound

Introduction

Patellofemoral Pain (PFP) is a common knee problem that is often seen in clinical practice, presenting with symptoms of anterior or retropatellar knee pain [1]. Causes of this condition are multifactorial, but are thought to include an imbalance between the vastus medialis (VM) and vastus lateralis (VL) [2], and abnormal morphology of structures in the knee joint [3]. The distal fibres of the VM, often referred to as the vastus medialis oblique (VMO), are thought to be important in maintaining patella alignment.

Estimates of the prevalence of PFP vary from 12% to 45% [4, 5]. It is most commonly seen in young, athletic females, although it can also be seen in males and non-athletic individuals. Insufficiency of the VMO is thought to be a contributing factor in PFP, and physiotherapy designed to target the VM is usually the first-line treatment [6, 7]. There is good evidence that VMO exercises help to alleviate the symptoms of PFP, [6, 8, 9] however there are limited data on the long-term results following knee rehabilitation.

There have been several studies using a validated ultrasound method [10] to investigate the

Received August 14, 2017; **Accepted** August 27, 2017; **Published** September 02, 2017

***Corresponding author:** Philip J Adds, Institute of Medical and Biomedical Education (Anatomy), St George's University of London, Cranmer Terrace, London SW17 0RE, United Kingdom, Tel num: +44 (0)2087255208; E-mail: padds@sgul.ac.uk

Citation: Arnantha H, Robertson C, Killingback A, Adds PJ (2017) Maintenance of exercise-induced changes in the architecture of the VMO: how much is enough? An *in-vivo* ultrasound study. Orthop Spine Sports Med (2017) 1:1 003

architecture of the VMO in symptomatic and asymptomatic individuals [11-14]. An i*n vivo* study using ultrasound has identified changes in VMO muscle architecture (fibre angle and patellar insertion ratio) following a six-week regime of physiotherapy [15]. There is however, no information in the literature regarding changes in the muscle architecture in the long term, either continuing with the training, reducing it, or abandoning it altogether once the patient has reached the end of the prescribed programme of physiotherapy. This means that healthcare professionals have little guidance when providing a treatment plan for patients with PFP.

The aim of this study was, therefore, to monitor the longer-term effects on changes to the VMO muscle architecture brought about by a six-week programme of physiotherapy, by cessation or reduction of the exercise regime, and to try to recommend the optimum amount of exercising necessary to maintain the changes to the VMO achieved by the exercise programme.

A cohort of 16 asymptomatic, young volunteers were recruited to take part in this study. Asymptomatic volunteers were chosen so that the possible effects of PFP on their ability to undertake exercises would not compound the variables of this study; and, since it has been shown that the effects of exercise are more marked in subjects with a low initial fibre angle [15], volunteers were screened for activity levels, and relatively sedentary individuals were chosen to participate in the study.

Exercises targeting the VMO for relief of PFP have been successful in previous trials, [16, 17] however there is conflicting evidence on whether open-chain kinetic exercises (OCKE) or closed-chain kinetic exercises (CCKE) are more effective for targeting the vastus medialis specifically, rather than also targeting the other muscles of the quadriceps group [6, 18, 19]. Although there have not been significant differences in the outcomes of OCKE and CCKE programmes [8], some individuals have reported more pain when using CCKE [9], hence an OCKE regime was used in this study.

Materials and Methods

Sixteen young, asymptomatic volunteers were recruited for this study, six males and ten females. Ethics approval was obtained from the local Research Ethics Committee, and the participants all gave informed consent. The following exclusion criteria were applied:

- Age < 18 or >30
- Previous quadriceps muscle injury
- Previous knee surgery or injury
- Previous or existing knee pain
- Previous or existing inflammatory conditions
- Tegner Score >4

The Tegner activity scale is a validated 10-point scale that quantifies an individual's level of activity [20], and is commonly used in the assessment of knee injuries [21]. A score of 4 or less, indicating a relatively sedentary individual, was a requirement for participation in this study.

Ultrasound procedure

A Philips iU22 ultrasound system (Serial No. 02KH9W) with a L17-5 linear array probe (Serial No. B07C4F) was used in this study.

The subject was examined in a supine position with their legs fully extended and relaxed on the ultrasound examination table. The subject's knees were immobilised by placing a pillow beneath their ankles.

The procedure described in previous studies [12-15] was followed. The parameters measured were: the VMO fibre angle in relation to the femoral axis, the length of the patella, and the insertion length (the length of the VMO insertion along the medial border of the patella with VMO fibres attached to it). Using the patella length and insertion length, the VMO insertion can be expressed as a percentage, the 'insertion ratio' (**Figure 1**).

The superior border of the patella (base) and the inferior border of the patella (apex) were palpated and marked on the skin. The patella length was then measured using digital callipers (resolution 0.01mm) (**Figure 2**). The mid-point of the patella was then determined with the callipers, and marked on the skin.

The femoral axis was determined by placing a one-metre metal ruler with the proximal end on the anterior superior iliac spine (ASIS) and the distal end passing through to the mid-point of the patella. A 10 cm line was then drawn on the skin from the inferior border of the patella towards the ASIS to represent the femoral axis (**Figure 2**).

The probe was carefully placed on the distal VMO and rotated until the fibres of the VMO were seen running parallel with each other on the ultrasound monitor; the angle of the probe relative to the femoral axis indicates the VMO fibre

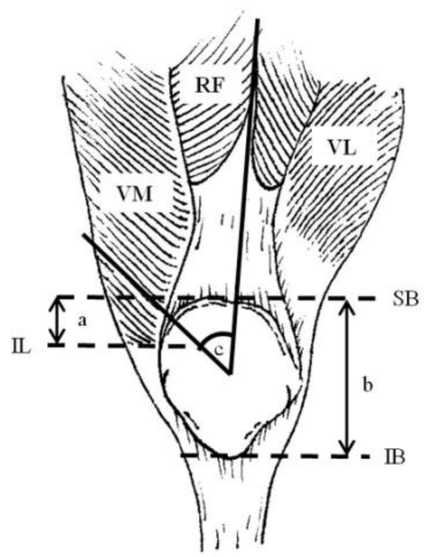

Figure 1: Drawing of the quadriceps to show VMO fibre angle and insertion length: a-insertion length, b-patella length, c-VMO fibre angle in relation to the femoral axis. SB- Superior border of patella, IB- inferior border of patella, VM – vastus medialis, RF – rectus femoris, VL –vastus lateralis, vertical black line indicates femoral axis. Insertion ratio (%) given by (a/b)*100. (Drawing by HA).

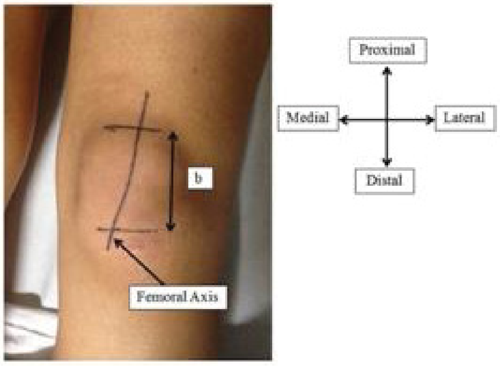

Figure 2: Superior and inferior borders of the patella and femoral axis marked on the skin. b- patella length.

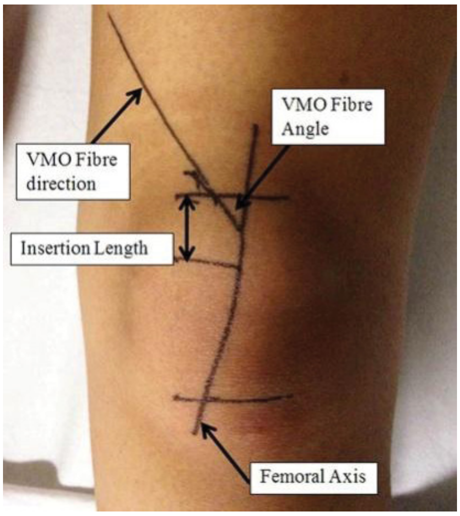

Figure 3: Femoral axis, VMO fibre direction and angle, and insertion length shown on subject's knee.

angle. The angle of the probe was marked, the probe was then removed and a straight line was drawn to intersect the femoral axis (**Figure 3**). The fibre angle was then measured with a transparent protractor.

The probe was then placed horizontally medial to the superior border of the patella and moved distally until the muscle fibres of the VMO could no longer be seen on the monitor. The position of the probe represented the distal extent of the VMO. As before, the position of the probe was marked on the skin, the probe was removed, and the distance between the probe level and the superior border of the patella (insertion length) was measured with digital callipers (**Figure 3**). The insertion ratio could then be calculated and expressed as a percentage by dividing the insertion length by the length of the patella.

Phase 1

Physical therapy programme: All 16 subjects underwent phase one of the trial involving a 6-week exercise programme tailored to reduce the symptoms of PFPS.

Exercise 1 – Knee extensions. The subjects lay in a supine position with a folded pillow beneath the knee to create a slight bend (**Figure 4a**). The subject then fully extended their knee and held the position for 10 seconds before returning to the rest position **Figure 4b**).

Exercise 2 – Isometric quadriceps contraction.

While in the supine position the subject placed a rolled towel (or equivalent) beneath their ankles (**Figure 5a**) and lay in a relaxed position. They then contracted their quadriceps, straightening the limb (**Figure 5b**); this position was held for 10 seconds before returning to a resting position.

Participants carried out 3 sets of between 12-20 reps of each exercise on both legs on the same day, every other day for a period of 6 weeks. Participants were given live demonstrations of the exercises as well as a point of contact to clear any uncertainty during the 6 weeks. Participants were requested to keep an exercise calendar to record their compliance. At any point should a participant feel pain or discomfort, they were asked to stop the exercise programme immediately and contact the study coordinator.

Upon completion of the 6 week exercise programme, all the participants had a second ultrasound scan to obtain the post-exercise measurements of VMO fibre angle, patella length and insertion length.

Phase 2

Following their second ultrasound session the participants were randomly allocated into one of four groups for the next six week:

Group EX0: stopped exercises completely.

Group EX1: continued the exercises once a week;

Group EX2: continued the exercises twice a week;

Group EX3: continued the exercises three times a week;

The exercises remained the same, and participants who continued with their exercises were told to spread the exercises out equally over the week.

Upon completion of the phase 2, a third ultrasound scan was carried out on all participants.

Intra-rater reliability study

To eliminate inter-rater variation, all ultrasound scanning was carried out by the same, trained operator. To assess the reliability of this operator's readings, an intra-rater reliability

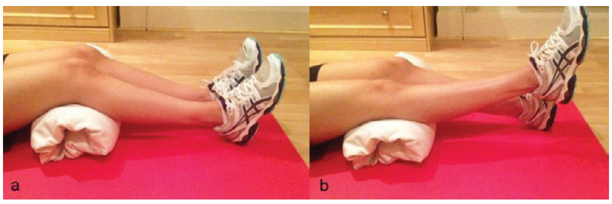

Figure 4: Knee extensions **a)** limb in resting position; **b)** leg in active extended position.

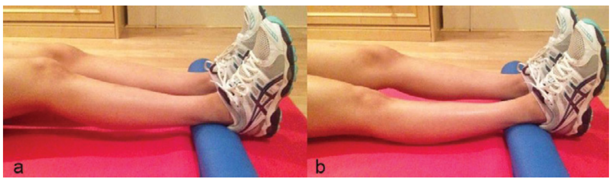

Figure 5: Isometric quadriceps contractions; **a)** Limb in relaxed position; **b)** right limb with quadriceps contracted.

study was carried out. A healthy individual matching the same exclusion criteria was selected to be scanned once a week for five weeks. The same measurements of the VMO angle, insertion length and patella length were taken. This individual did not take part in the exercise programme; therefore changes in the architecture of the VMO were not expected. The coefficient of variance (CV) was calculated.

Statistical analysis

Data were analysed for normal distribution using the Shapiro-Wilk test. Data from the first phase of the programme were analysed using a t-test to identify if changes in the VMO fibre angle and insertion ratio were statistically significant. Data from the second phase of the programme were analysed using one-way analysis of variance (ANOVA) to determine if any differences of VMO fibre angle and insertion ratio were significant. An unpaired t-test was used to compare results between different groups. Statistical analysis was carried out using SPSS v24.0 (IBM SPSS Statistics).

Results

Intra-rater reliability study

The coefficients of variance were: 0.009 (patella length), 0.03(VMO insertion length) and 0.01(VMO fibre angle). A coefficient of variance of less than 0.05 indicates that the results collected by this operator were highly reliable.

Anthropometric data

Ten female and 6 male, relatively sedentary, subjects were eligible for the study and each gave informed consent. The average Tegner activity score for participants was 3.35 (range 2-4). The anthropometric data are given in Table 1.

Phase 1 - VMO angle change: The mean VMO angle prior to exercise was found to be 61.5°, range 49°-70°. After the exercise programme the average VMO angle increased to 65.9°, range 59°-74° ($p < 0.001$) (Table 2).

Phase 1-VMO insertion ratio: The mean VMO insertion ratio prior to exercise was found to be 40.11% (range 23.52%-53.38%). After the exercise programme the average insertion ratio increased to 40.20% (range 24.10%-63.26%). This change was not statistically significant (p=0.9202) (Table 2).

Phase 1- Compliance: The self-reported compliance exercise calendar for phase 1 indicated an average compliance of 91.25%±11.85 (range 60-100).

Phase 2 – VMO angle change: The Shapiro-Wilk test showed that results data were normally distributed ($p > 0.05$).

On average the group which stopped all exercises (group EX0) saw a decrease in fibre angle of 5.88° (range: -13°-(-2°)). The group which continued the exercises once a week (EX1) saw a reduction in fibre angle of -2.5° (range: - 5°-0°). The group which continued to exercise twice a week (EX2) showed the least change with an average increase of fibre angle of 0.75° (range: -2° - +2°). The group which continued exercises three times a week (EX3) showed a further increase in average VMO fibre angle of 3.13° (range 1°-8°) ($p<0.001$, Table 3). There was found to be a strong correlation between VMO angle change and the number of days of exercise per week ($R^2 = 0.994$) (Figure 6).

Phase 2 – VMO insertion ratio: There were changes in the insertion ratio, however, these changes were not found to be statistically significant (p=0.347). For group EX0 the VMO insertion ratio increased by 0.20% (range -12.96% -

	Age (Years)	Weight (kg)	Height(m)	BMI	Tegner Score
Mean ± SD	18.82±1.28	67.71±9.42	1.72±0.09	22.95±2.39	3.35±0.61
Range	18-23	56-87	1.58-1.89	18.82-28.09	02-Apr

Table 1. Anthropometric details for subjects in the study.

	Mean ± SD	Range
Initial VMO angle (°)	61.5±5.05	49-70
Final VMO angle (°)	65.9±4.92	59-74
VMO angle change	4.4±3.01**	-13
Initial insertion ratio (%)	40.11±8.88	23.52-53.38
Final insertion ratio (%)	40.20±10.21	24.10-63.26
Insertion ratio change (%)	0.09±5.25 (ns)	-16.91

Table 2: VMO fibre angle and insertion ratio: initial and final values and change, in in phase 1 of the study. ** p<0.001, ns no significance.

	Fibre angle change(°) (mean ± SD)	Fibre angle change (range)	Insertion ratio change (mean ± SD)	Insertion ratio change (range)	Compliance (mean ± SD)	Compliance (range)
Group EX0	-5.88±3.27**	-11	0.20±5.52 ns	-19.42	100±0	100-100
Group EX1	-2.5±1.93**	-5	0.39±3.24 ns	-10.81	95.00±9.26	80-100
Group EX2	0.75±1.28**	-4	4.38±4.58 ns	-15.09	93.75±7.39	83.33-100
Group EX3	3.13±2.23**	01-Aug	2.24±6.63 ns	-17.78	87.50±8.77	78-100

Table 3: VMO fibre angle and insertion ratio, and self-reported compliance for the 4 groups after phase 2 of the study. EX0, no exercise, EX1 exercised once a week, EX2 exercised twice a week, EX3 exercised 3 times a week. ** p<0.001, ns no significance.

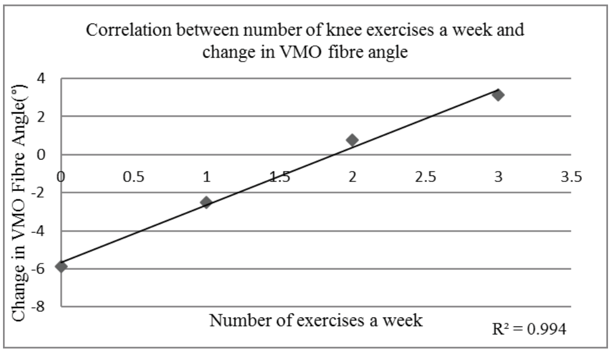

Figure 6: Scatter plot showing the relationship between the number of exercises performed per week and the change in VMO fibre angle (°).

6.46%). Group EX1 showed an increase in insertion ratio of 0.39% (range -3.62% - 7.19%). Group EX2 demonstrated an increase in VMO insertion ratio of 4.38% (range -4.36% - 10.73%). Group EX3 also saw an increase in VMO insertion ratio by 2.24% (range -9.32% - 8.46%) (**Table 3**).

Comparing groups using an unpaired t-test, EX0 compared to EX1 was not significant, EX1 compared to EX2 was significant ($p<0.05$), and EX2 compared to EX3 was not significant.

Phase 2 – compliance: Average overall compliance for all groups was 94.06%, (range 78%-100%) (**Table 3**).

Discussion

This study aimed to identify the effects of OCKE on the architecture of the VMO in non-pathological individuals, and, furthermore, to determine the minimum amount of exercise required post-rehabilitation to maintain any changes achieved in muscle architecture. It is common in clinical practice to provide physiotherapy as a first line treatment for sufferers of PFP [8, 22]. Although the exact cause of PFP is uncertain, atrophy of the VMO is thought to be a contributory factor [23], hence the use of VMO targeting exercises for patients presenting with PFP.

It has been shown that the insertion level, fibre angle and muscle volume were all significantly smaller in a group of patients with PFP syndrome [12]. Although physiotherapy targeting the VMO has shown significant improvements in PFP symptoms within a short period of time [16], chronic or recurrent symptoms usually require continuous VMO training [24]. This study has shown a significant difference in VMO fibre angle following 6 weeks of OCKE training; and, furthermore, that it was necessary to continue exercising a minimum of twice a week in order to maintain the fibre angle change that was achieved after the initial six-week exercise programme.

VMO fibre angle

The average initial VMO fibre angle for the relatively sedentary participants in this investigation was 61.5°, which is consistent with previous literature [14, 15]. Previous studies have demonstrated hypertrophy and an increase in the angle of pennation in the VM and other muscles following strength training [15, 25]. An increase in VMO fibre angle was therefore to be expected following phase 1 of this trial, which was found to be the case: the average fibre angled increased by 4.4° from 61.5° to 65.9° ($p<0.001$). This is in line with the 5.24° increase reported by Khoshkhoo et al. [15] following a similar exercise regime. It would not be unreasonable, therefore, to expect changes in VMO fibre angle of this order in PFP patients who have completed a physiotherapy programme such as that described here. The aim of phase 2 of this trial was to quantify the level of activity that would be necessary to maintain the changes in the muscle architecture achieved during phase 1.

Taaffe *et al.* [26] conducted a 24-week quadriceps training programme; 24 weeks after cessation of training, a reduction in strength of 7.7% was reported. Narici *et al.* [27] reported that quadriceps atrophy was associated with a reduction in pennation angle of 16%. In our study, complete cessation of the exercises (group EX0) led to an average reduction in VMO fibre angle of 5.88°, back to below the former baseline. In group EX1 (who completed the exercises once a week) the VMO fibre angle was reduced by 2.5°, a loss of over half the increase achieved during phase 1.

Subjects in group EX2 (exercising twice a week), however, saw a slight increase in fibre angle (0.75°), and there was a statistically significant difference when comparing the results from groups EX1 and EX2. Group EX3 (exercising three times a week) achieved an increase of a further 3.13°. On that basis we would recommend continuation of physiotherapy twice a week following an initial six-week programme, in order to maintain the increase in fibre angle already achieved.

Insertion ratio

This study indicated an average initial insertion ratio of 40.11% prior to exercise and 40.20% after phase 1, an insignificant difference. Differences following phase 2 were also not significant. It is difficult to know how to interpret these results. While Benjafield et al. [14] reported insertion ratios that were not significantly different in sedentary and athletic subgroups, Khoshkhoo et al. [15] reported a significant change following a similar quadriceps strengthening regime. From the results reported here it would appear that neither short-term nor long term exercises have an influence on the insertion ratio. An unusual finding was that in group EX0, there was a slight increase in average insertion ratio six weeks after cessation of the exercises.

Although it has been suggested that the greater the insertion ratio, the greater the stability of the patella, it has also been shown that 25% of pathological knees had an insertion ratio of greater than 60% [28]. Jan et al., [12] on the other hand, reported that lower insertion ratios tend to be associated with PFP, and ratios as low as 17.3% have been reported in symptomatic individuals [29]. From these apparently conflicting data it could be hypothesised that PFP may be associated with insertion ratios at either the lower or higher extremes of the range.

In summary, the results of this study show that it is necessary to continue exercising twice a week to maintain the gains achieved in a six-week quadriceps strengthening physiotherapy programme. This information is valuable evidence which healthcare professionals may want to incorporate to optimise long-term treatment plans for patients presenting with PFP.

Limitations

The main limitation in this study was the limited sample size (n=16). A larger sample would have given more statistical weight to the study. Even though the overall compliance was close to 94.06% for phase 2 and 91.25% for phase 1, this was a self-reported compliance level, which relied on the participants remembering to do their exercises and to mark the calendar truthfully.

Ethical Approval

This study was granted ethical approval by the Chair of the Research Ethics Committee at St George's University of London.

Funding

Internally funded by St George's, University of London.

Conflict of interest

The authors have no conflicts of interest to declare.

References

1. Wilson T (2007) The measurement of patellar alignment in patellofemoral pain syndrome: are we confusing assumptions with evidence? J Orthop Sports Phys Ther 37: 330-341.
2. McConnell J (2007) Rehabilitation and nonoperative treatment of patellar instability. Sports Med Arthrosc 15: 95-104.
3. Cutbill JW, Ladly KO, Bray RC, Thorne P, Verhoef M (1997) Anterior knee pain: a review. Clin J Sport Med 7: 40-45.
4. Cook C, Hegedus E, Hawkins R, Scovell F, Wyland D (2010) Diagnostic accuracy and association to disability of clinical test findings associated with patellofemoral pain syndrome. Physiother Can 62: 17-24.
5. Roush JR, Curtis Bay R (2012) Prevalence of anterior knee pain in 18–35 year-old females. Int J Sports Phys Ther 7: 396-401.
6. Tang SF, Chen CK, Hsu R, Chou SW, Hong WH, et ak. (2001) Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercises in patients with patellofemoral pain syndrome: an electromyographic study. Arch Phys Med Rehabil 82: 1441-1445.
7. Thomee P, Thomee R, Karlsson J (2002) Patellofemoral pain syndrome: pain, coping strategies and degree of well-being. Scand J Med Sci Sports 12: 276-81.
8. Mason M, Keays SL, Newcombe PA (2011) The effect of taping, quadriceps strengthening, and stretching prescribed separately or combined on patellofemoral pain. Physiother 16: 109-119.
9. Post WR (2005) Patellofemoral Pain. Results of nonoperative treatment. Clin Orthop Rel Res 436: 55-59.
10. Engelina S, Robertson CJ, Moggridge J, Killingback A, Adds PJ (2014) Using ultrasound to measure the fibre angle of vastus medialis oblique: a cadaveric validation study. Knee 21: 107-111.
11. Lin Y, Lin J, Cheng C, Lin D, Jan M (2008) Association between sonographic morphology of vastus medialis obliquus and patellar alignment in patients with patellofemoral pain syndrome. Orthop Sports Phys Ther 38: 196-202.
12. Jan MH, Lin DH, Lin JJ, Lin CH, Cheng CK, et al. (2009) Differences in sonographic characteristics of the vastus medialis obliquus between patients with patellofemoral pain syndrome and healthy adults. Am J Sports Med 37: 1743-1749.
13. Engelina S, Antonios T, Robertson CJ, Killingback A, Adds PJ (2014) Ultrasound investigation of vastus medialis oblique muscle architecture: an in vivo study. Clin Anat 27: 1076-1084.
14. Benjafield AJ, Killingback A, Robertson CJ, Adds PJ (2015) An investigation into the architecture of the vastus medialis oblique muscle in athletic and sedentary individuals: an in vivo ultrasound study. Clin Anat 28: 262-268.
15. Khoshkhoo M, Killingback A, Robertson CJ, Adds PJ (2016) The effect of exercise on vastus medialis oblique muscle architecture: an ultrasound investigation. Clin Anat 29: 752-758.
16. Syme G, Rowe P, Martin D, Daly G (2009) Disability in patients with chronic patellofemoral pain syndrome: a randomised controlled trial of VMO selective training versus general quadriceps strengthening. Manual Ther 14: 252-263.
17. Chang W, Chen F, Lee C, Lin H, Lai P (2014) Effects of kinesio taping versus McConnell taping for patellofemoral pain syndrome: a systematic review and meta-analysis. Evid Based Complement Alternat Med 11.
18. Irish SE, Millward AJ, Wride J, Haas BM, Shum GL (2010) The effect of closed-kinetic chain exercises and open-kinetic chain exercise on the muscle activity of vastus medialis oblique and vastus lateralis. J Strength Cond Res 24: 1256-1262.
19. Minoonejad H, Rajabi R, Ebrahimi-Takamjani E, Alizadeh MH, Jamshidi AA, et al. (2012) Combined open and closed kinetic chain exercises for patellofemoral pain syndrome: a randomized controlled trial. World J Sport Sci 6: 278-285.
20. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res 198: 43-49.
21. Briggs KK, Steadman JR, Hay CJ, Hines SL (2009) Lysholm score and Tegner activity level in individuals with normal knees. Am J Sports Med 37: 898-901.
22. Dixit S, DiFiori J, Burton M, Mines B (2007) Management of patellofemoral pain syndrome. Am Fam Physician 75: 194-202.
23. Pattyn E, Verdonk P, Steyaert A, Vanden Bossche L, Van den Broecke W, et al. (2011) Vastus medialis obliquus atrophy: does it exist in patellofemoral pain syndrome? Am J Sports Med 39: 1450-1455.
24. Kannus P, Natri A, Paakkala T, Jarvinen M (1999) An outcome study of chronic patellofemoral pain syndrome. Seven-year follow-up of patients in a randomized, controlled trial. J Bone Joint Surg Am 81: 355-363.
25. Aagaard P, Andersen JL, Leffers AM, Wagner Å, Magnusson SP, et al. (2001) A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. J Physiol 534: 613-623.
26. Taaffe DR, Henwood TR, Nalls MA, Walker DG, Lang TF, et al. (2009) Alterations in muscle attenuation following detraining and retraining in resistance trained older adults. Gerontology 55: 217-223.
27. Narici MV, Roi GS, Landoni L, Minetti AE, Cerretelli P (1989) Changes in force, cross sectional area and neural activation during strength training and detraining of the human quadriceps. Eur Appl Physiol 59: 310-319.

28. Holt G, Nunn T, Allen RA, Forrester AW, Gregori A (2008) Variation of the vastus medialis obliquus insertion and its relevance to minimally invasive total knee arthroplasty. J Arthroplasty 23: 600-604.

29. Watanabe N, Narita W, Namura T, Ito H, Nishimura T, et al. (2008) Anatomical assessment of the vastus medialis oblique muscle in patients with osteoarthritis of the knee. Arthroplasty 23: 287.