J. Phys. Ther. Sci. 34: 161–166, 2022

The Journal of Physical Therapy Science

Original Article

The effect of stretching exercises on the fibre angle of the vastus lateralis and vastus medialis oblique: an ultrasound study

Jordan Bethel[1)], Alban Killingback[2)], Claire Robertson[3)], Philip J Adds[1)*]

[1)] *Institute of Medical and Biomedical Education (Anatomy), St George's, University of London: Cranmer Terrace, London SW17 0RE, UK*
[2)] *Department of Medical Physics, St George's Hospital NHS Trust, UK*
[3)] *Wimbledon Clinics, UK*

Abstract. [Purpose] To investigate the effects of a seven-week quadriceps stretching program on the muscle fibre orientation of the vastus medialis oblique and vastus lateralis in the lower limbs by ultrasound imaging. [Participants and Methods] Twenty-seven healthy, physically fit, asymptomatic females and males (age 21.5 ± 1.3, Tegner activity level score ≥4) were recruited. Their initial vastus medialis oblique and vastus lateralis fibre angles were determined using ultrasound. They then undertook a seven-week quadriceps stretching program, 3 sets of stretches to be performed on both lower limbs, 3 times a week on 3 separate days. One volunteer was assigned as an intra-rater control and did not take part in the stretching program. The vastus lateralis and vastus medialis oblique fibre angles were measured again on completion of the exercise regime. [Results] A statistically significant decrease in muscle fibre angle was observed in both the right and left vastus medialis oblique, and the right and left vastus lateralis. [Conclusion] A 7-week stretching program can result in a significant decrease in muscle fibre angle in both the vastus medialis oblique and the vastus lateralis. This can help in understanding the effects of prescribed stretching exercises on athletic patients with PFP.

Key words: Muscle fibre angle, Stretching exercises, Ultrasound

(This article was submitted Sep. 27, 2021, and was accepted Nov. 25, 2021)

INTRODUCTION

The vastus medialis (VM) and vastus lateralis (VL) are constituent muscles of the quadriceps femoris group in the anterior thigh. By convention, the VM is often subdivided into two parts, the vastus medialis longus (VML) and the vastus medialis oblique (VMO), due to the different orientation of the muscle fibres. This change in fibre orientation was described by Leib & Perry[1)] and has been further validated in more recent literature[2–4)]. The VM and VL, with the other muscles of the quadriceps, are active in extension of the knee joint, however, the VM and VL are also considered to be important in the functioning of the patellofemoral joint, and the maintenance of patellar tracking in the trochlear of the femur. The VMO in particular has been the object of much research due to its role in patellar tracking, where it exerts a medial pull to maintain the patella in the trochlear groove[5, 6)], countering the lateral forces generated by the other muscles of the quadriceps group.

Research into the VL is limited compared to the VM, however, it is also considered to consist of two parts with distinct muscle fibre orientation, and much like the VM, the vastus lateralis longus (VLL) and vastus lateralis oblique (VLO) exert forces at different angles relative to the femoral axis[2, 7, 8)].

Patellofemoral pain (PFP) is a diagnosis that describes non-specific anterior knee pain in the retro-patellar region and can present as a variety of symptoms[9, 10)]. It is one of the most common musculoskeletal complaints seen clinically, with an

---

*Corresponding author. Philip Adds (E-mail: philadds.anatomy@gmail.com) estimated annual prevalence in the general population of 22.7%, (females 29.2%, males 15.5%) in the UK11); it is the most common cause of knee pain in young athletic individuals, and particularly affects females10, 12).

There are a variety of possible causes of PFP, including overuse, trauma, muscle dysfunction, malalignment, patellar hypermobility, poor quadriceps flexibility, and an increased Q angle8, 10, 13). However, the exact aetiology remains unclear, and it is likely to be multi-factorial8). The prevalence of PFP in young athletic individuals can be attributed to overloading or overuse of the knee joint, leading to imbalances in the forces responsible for patellar tracking during flexion and extension of the knee13).

Since PFP can arise from patellar maltracking due to either insufficiency of the VMO, or hypertrophy of the VL, first line treatment options include targeted physiotherapy either to strengthen the VMO, or to reduce tension in the VL by stretching14, 15). The risk of course, is that exercises to strengthen the VMO may also have an unwanted strengthening effect on the VL, and equally, that exercises to stretch the VL may also lead to stretching of the VM and a concomitant reduction of tone in the VMO.

Previous studies shown that the fibre angle of the VMO increases in response to exercise16), as well as being generally greater in athletic individuals than in sedentary individuals17). However, no studies could be found investigating the effect of exercise on the muscle fibre angle of the VL. Equally, no studies could be found on the effect of stretching exercises on the fibre angle of the VMO, although e Lima et al.18) investigated the effect of stretching on the VL.

The aim of this study, therefore, was to investigate the effect of a seven-week stretching program that targeted the quadriceps muscles using *in-vivo* ultrasonography, to determine changes in fibre angle orientation in both the VMO and VL.

Ultrasonography is a safe, non-invasive imaging modality that has been used in many previous studies to undertake *in-vivo* measurements of the VM and VL16, 18, 19); it has also been validated in a cadaveric study on the architecture of the VM20).

This study recruited young athletic individuals, as this targeted the group in which PFP is most prevalent, and would, therefore, provide a more relevant data set than using older, or mixed, ages.

PARTICIPANTS AND METHODS

Twenty-seven athletic male volunteers, aged 18–35 years, were recruited to participate in this study. Each volunteer gave informed consent and completed an initial health questionnaire. Exclusion criteria included: no previous knee surgery on either limb, no current knee pathology, and a Tegner activity level score <421), indicating a sedentary occupation and no active participation in sports or training. Participants were given an information sheet, exercise instructions, and a compliance diary. Ethical approval was granted by the host institution.

All participants underwent an initial US scan of their VL and VM to record the baseline fibre angles. Participants, wearing shorts, lay in the supine position on an examination couch with a pillow beneath their ankles to maintain stability. The centre of the patella was located using a digital calliper (Duratool) and marked with a skin pen. A steel ruler was placed between the ASIS and the centre of the ipsilateral patella, and a line was marked on the skin to represent the femoral axis (Fig. 1).

The distal thigh was then scanned with a Philips iU22 ultrasound machine with a L17-5 linear array probe to identify and mark the fibre angle of the VL and VMO, respectively. The probe was aligned with the muscle fibres, and its position was marked on the skin (Fig. 2). The fibre angle with respect to the femoral axis was then measured with a clear plastic protractor (Fig. 3). Each measurement was repeated three times. To minimise error, all measurements were taken by the same trained operator, using the same equipment.

Fig. 1. The femoral axis was drawn with a straight line from the ASIS through the midpoint of the patella.

Participants then began a seven-week stretching program, on three separate days a week. The participants were asked to steady themselves against a wall, and take their right foot with their right hand, and pull it towards their buttocks until a light stretch was felt down the front of their thigh. They then had to push their foot back against their hand as hard as they could for ten seconds, then relax and pull their foot forward again as far as possible until they once again felt a light stretch. This was to be done three times, then repeated with the left leg (Fig. 4). This technique is known as hold-relax, and is well documented in the literature as being efficacious for increasing flexibility[22].

Immediately upon completion of the seven-week stretching program, each participant was scanned again, and their VL and VMO fibre angles measured for the second time. The measurements were taken by the same investigator, using the same equipment and method as the initial scan.

One randomly selected volunteer acted as an intra-rater control. This individual did not take part in the stretching program and was scanned on four separate occasions over seven days.

A power calculation showed that a minimum of 24 volunteers were required for statistical significance. The coefficient of variance (SD/mean) was calculated for the intra-rater reliability study. The difference in VL and VMO fibre angles pre- and post-exercise, and between the VL and VMO angle change on the same limb, were analysed with a paired t-test. Linear regression was used to analyse the correlation between initial fibre angle and change in fibre angle, and between compliance and fibre angle change.

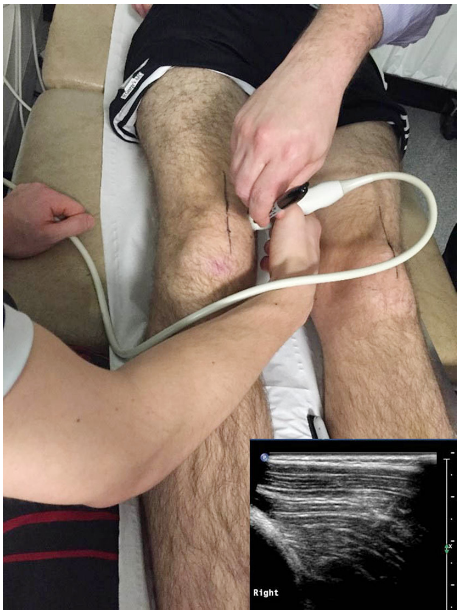

Fig. 2. With the ultrasound probe positioned parallel to the orientation of the underlying muscle fibres (inset) a line was drawn to intersect with the femoral axis.

Fig. 3. The muscle fibre angle was measured with respect to the femoral axis.

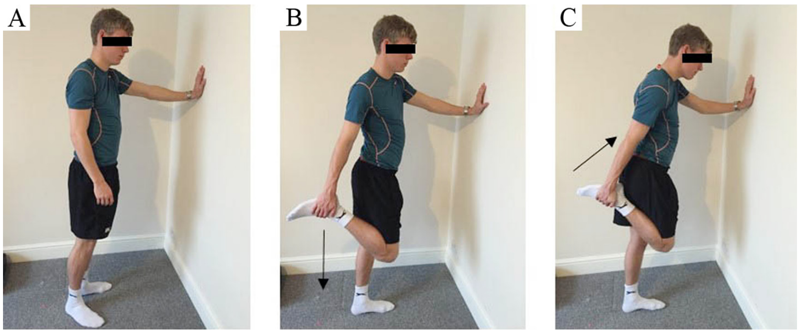

Fig. 4. Targeted quadriceps stretch. (A) Stand next to wall; (B) pull foot towards buttocks, then push back against hand for 10 sec; (C) relax quadriceps and pull foot as close to buttocks as possible for 10 sec.

RESULTS

There was a high degree of reliability in the VMO measurements with a coefficient of variance of 0.039 and 0.048 for the right and left VMO angle, respectively. The coefficient of variance for the VL was higher, at 0.15 and 0.12 for the right and left VL, respectively (Table 1).

There was a mean decrease of 3.81° (± 7.54) in VMO fibre angle in the right limb ($p<0.05$), and a mean decrease of 5.99° (± 7.03) in the left limb ($p<0.001$) (Table 2).

There was a mean decrease of 7.52° (± 8.65) in VL fibre angle in the right limb ($p<0.001$), and mean decrease of 7.93° (± 8.93) in the left limb ($p<0.001$) (Table 3).

There was found to be no significant difference between the change in fibre angle of the VL and VMO on the same limb ($p>0.05$ for both right and left lower limbs).

There was a moderate negative correlation between the initial muscle fibre angle and angle change after stretching in the right VMO ($R^2=-0.5443$), and a slightly weaker correlation in the left VMO ($R^2=-0.3941$) (Fig. 5).

There was a stronger correlation between the initial angle of the VL and amount of change following stretching in both the right ($R^2=-0.8564$) and left ($R^2=-0.8582$) lower limbs (Fig. 6).

Average compliance from the subjects' compliance diaries was 110.16%. However, there was found to be a weak negative correlation between compliance and fibre angle change in the right VMO ($R^2=-0.1728$) and left VMO ($R^2=-0.0121$). There was a slightly stronger positive correlation in the right ($R^2=0.1915$) and left ($R^2=0.3105$) VL.

DISCUSSION

Patellofemoral pain is common in young athletic individuals and may be caused by an imbalance between the VL and VMO, leading to patellar maltracking[8, 13, 23)]. In patients with VMO insufficiency, first line treatment may involve exercises that target the VM in order to strengthen the VMO and hence, resist the lateralisation of the VL. Conversely, in patients with hypertrophy of the VL, stretching exercises to reduce the tension in the VL maybe recommended. Previous studies have shown that exercises to stretch the quadriceps significantly decrease knee pain and improve joint function in patients with PFP[24, 25)].

It has been shown in previous studies that strengthening exercises targeting the VM lead to an increase in the angle of pennation of the VMO[16, 26)] (detectable as an increase in the angle of the muscle fibres relative to the femoral axis); exercises to stretch the VL were found to cause no significant change in in the angle of pennation of the VL in a small-scale study on the right lower limb of 12 participants[18)].

There appears to be no information in the literature regarding the effects of stretching exercises on the fibre angle of the VL and VMO together. Since strengthening exercises cause an increase in fibre angle, a reduction in the same angle may be

Table 1. Intra-rater reliability study, measurements repeated 4 times over 7 days

	Mean	Standard deviation (SD)	Coefficient of variance
VMO fibre angle (°) R	62.92	2.46	0.039
VMO fibre angle (°) L	61.33	2.92	0.048
VL fibre angle (°) R	39.25	5.97	0.15
VL fibre angle (°) L	39.33	4.84	0.12

Table 2. VMO fibre angle change following 7-week stretching program

	Mean	Standard Deviation	Range
VMO fibre angle change (°) R	−3.81*	7.54	−21.33 to 11.33
VMO fibre angle change (°) L	−5.99***	7.03	−22.33 to 3.33

*$p<0.05$, **$p<0.01$, ***$p<0.001$.

Table 3. VL fibre angle change following 7-week stretching program

	Mean	SD	Range
VL fibre angle change (°) R	−7.52***	8.65	−26.66 to 10.66
VL fibre angle change (°) L	−7.93***	8.93	−27.33 to 7.33

***$p<0.001$.

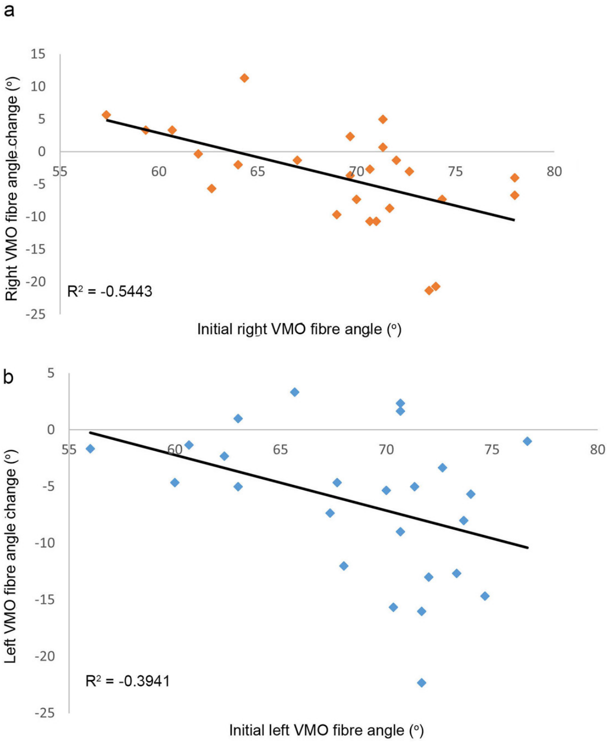

Fig. 5. Scatter plot showing the relationship between the initial VMO fibre angle and the change in fibre angle post-exercise, in the right (a) and left (b) lower limb.

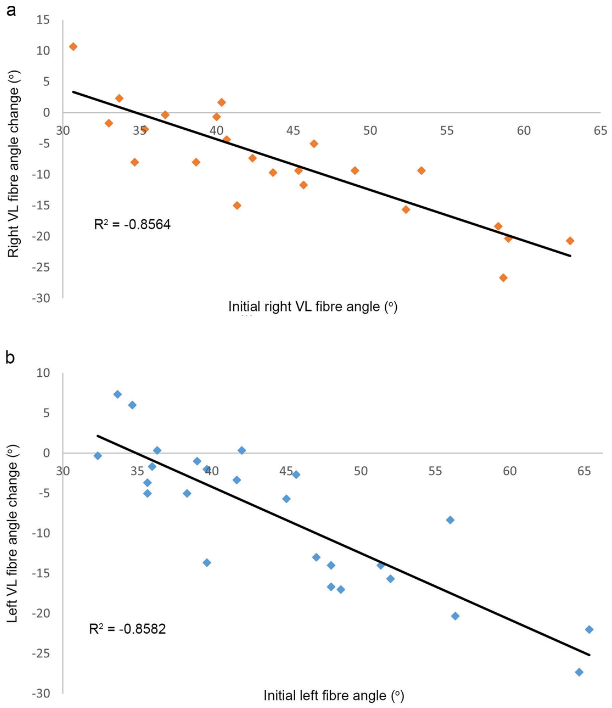

Fig. 6. Scatter plot showing the relationship between the initial VL fibre angle and the change in fibre angle post-exercise, in the right (a) and left (b) lower limb.

taken as an indication of weakening, or at least a reduction in tone, of the muscle, and is, therefore, something that should ideally be avoided for the VM.The study reported here recruited twenty-seven healthy, young athletic male volunteers who would likely be prescribed stretching exercises if they were diagnosed with PFP, and if VL hypertrophy was suspected. The results reported here, then, would be relevant to the impact of stretching on the muscle architecture of this potential patient population in a clinical environment.

We have shown that there was a statistically significant change in muscle fibre angle in both the right and left VMO, and right and left VL muscles, following a seven-week stretching program. This contrasts with the findings of e Lima et al.[18)] who found no significant change in VL fibre orientation after a stretching program of leg flexor and extensor stretches. This may be due to their small sample size, with measurements being taken from only 12 lower limbs, in contrast to the 52 limbs measured here. There may also have been differences in the stretching programs used.

The results of this study are of particular significance when considering the effect of patellar maltracking in PFP due to a hypertrophied VL and/or a weakened VMO. We found no significant difference between the changes in muscle fibre angle in the VMO and VL in the same limb, following stretching. This suggests that any existing imbalance would not be altered by stretching, but that the fibre orientation of both the VMO and VL will decrease to a more or less equal degree.

There was a moderate negative correlation between initial VMO fibre angle and amount of fibre angle change, and a strong negative correlation between initial VL fibre angle and amount of fibre angle change. This suggests that initial fibre angle a could be predictor for the type of PFP patients who would benefit most from a stretching program as part of their rehabilitation; such patients can be easily identified by an initial US screening scan in clinic.

This study had some limitations. We relied on the study group to carry out a stretching exercise program over a seven-week period, and, although they were each given a compliance diary, which has been shown to increase compliance[27)], we nonetheless had to rely on the participants to record their compliance accurately and carry out their exercises as prescribed. Although the average recorded compliance was in excess of 100%, indicating that several participants performed quadriceps stretches beyond the required number, the clinical reality is that adherence in very likely to be below 100%. Also, all the participants of the study were actively taking part in a range of different sports and/or exercise throughout the seven-week period; the amount and intensity was not monitored, and this could have affected the results.

This study investigated males. It would be useful to repeat the study with females, especially given that PFP is more prevalent amongst females. Ultimately, it would be useful to see if the effect is similar in the symptomatic PFP population and if subjects can tolerate the hold-relax technique. Hold-relax could also be compared to other commonly used interventions for flexibility, such as contract relax, static stretching, and eccentric loading.

In conclusion, this is the first study in the literature to show a statistically significant decrease in muscle fibre orientation in the right and left VMO muscles, as well as in the right and left VL muscles, in response to a seven-week stretching program ($p<0.05$). There was no significant difference in the decrease in fibre angle between the VMO and VL on the same limb.

Funding

This study was funded internally by St George's, University of London.

Conflicts of interest

The authors have no conflict of interests to declare.

REFERENCES

1) Lieb FJ, Perry J: Quadriceps function. An anatomical and mechanical study using amputated limbs. J Bone Joint Surg Am, 1968, 50: 1535–1548. [Medline] [CrossRef]
2) Weinstabl R, Scharf W, Firbas W: The extensor apparatus of the knee joint and its peripheral vasti: anatomic investigation and clinical relevance. Surg Radiol Anat, 1989, 11: 17–22. [Medline] [CrossRef]
3) Smith TO, Nichols R, Harle D, et al.: Do the vastus medialis obliquus and vastus medialis longus really exist? A systematic review. Clin Anat, 2009, 22: 183–199. [Medline] [CrossRef]
4) Skinner EJ, Adds PJ: Vastus medialis: a reappraisal of VMO and VML. J Phys Ther Sci, 2012, 24: 475–479. [CrossRef]
5) Nozic M, Mitchell J, de Klerk D: A comparison of the proximal and distal parts of the vastus medialis muscle. Aust J Physiother, 1997, 43: 277–281. [Medline] [CrossRef]
6) Amis AA: Current concepts on anatomy and biomechanics of patellar stability. Sports Med Arthrosc Rev, 2007, 15: 48–56. [Medline] [CrossRef]
7) Bennett WF, Doherty N, Hallisey MJ, et al.: Insertion orientation of terminal vastus lateralis obliquus and vastus medialis obliquus muscle fibres in human knees. Clin Anat, 1993, 6: 129–134. [CrossRef]
8) Waryasz GR, McDermott AY: Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. Dyn Med, 2008, 7: 9. [Medline] [CrossRef]
9) Thomeé R, Augustsson J, Karlsson J: Patellofemoral pain syndrome: a review of current issues. Sports Med, 1999, 28: 245–262. [Medline] [CrossRef]
10) Cook C, Hegedus E, Hawkins R, et al.: Diagnostic accuracy and association to disability of clinical test findings associated with patellofemoral pain syndrome. Physiother Can, 2010, 62: 17–24. [Medline] [CrossRef]
11) Dey P, Callaghan M, Cook N, et al.: A questionnaire to identify patellofemoral pain in the community: an exploration of measurement properties. BMC Musculoskelet Disord, 2016, 17: 237. [Medline] [CrossRef]
12) Boling M, Padua D, Marshall S, et al.: Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scand J Med Sci Sports, 2010, 20: 725–730. [Medline] [CrossRef]
13) Dixit S, DiFiori JP, Burton M, et al.: Management of patellofemoral pain syndrome. Am Fam Physician, 2007, 75: 194–202. [Medline]
14) Bhave A, Baker E: Prescribing quality patellofemoral rehabilitation before advocating operative care. Orthop Clin North Am, 2008, 39: 275–285, v. [Medline] [CrossRef]
15) Al-Hakim W, Jaiswal PK, Khan W, et al.: The non-operative treatment of anterior knee pain. Open Orthop J, 2012, 6: 320–326. [Medline] [CrossRef]
16) Khoshkhoo M, Killingback A, Robertson CJ, et al.: The effect of exercise on vastus medialis oblique muscle architecture: an ultrasound investigation. Clin Anat, 2016, 29: 752–758. [Medline] [CrossRef]
17) Benjafield AJ, Killingback A, Robertson CJ, et al.: An investigation into the architecture of the vastus medialis oblique muscle in athletic and sedentary individuals: an in vivo ultrasound study. Clin Anat, 2015, 28: 262–268. [Medline] [CrossRef]
18) e Lima KM, Carneiro SP, Alves DS, et al.: Assessment of muscle architecture of the biceps femoris and vastus lateralis by ultrasound after a chronic stretching programme. Clin J Sport Med, 2015, 25: 55–60. [CrossRef]
19) Engelina S, Antonios T, Robertson CJ, et al.: Ultrasound investigation of vastus medialis oblique muscle architecture: an in vivo study. Clin Anat, 2014, 27: 1076–1084. [Medline] [CrossRef]
20) Engelina S, Robertson CJ, Moggridge J, et al.: Using ultrasound to measure the fibre angle of vastus medialis oblique: a cadaveric validation study. Knee, 2014, 21: 107–111. [Medline] [CrossRef]
21) Tegner Y, Lysholm J: Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res, 1985, (198): 43–49. [Medline]
22) Cayco CS, Labro AV, Gorgon EJ: Hold-relax and contract-relax stretching for hamstrings flexibility: a systematic review with meta-analysis. Phys Ther Sport, 2019, 35: 42–55. [Medline] [CrossRef]
23) Lin F, Wilson NA, Makhsous M, et al.: In vivo patellar tracking induced by individual quadriceps components in individuals with patellofemoral pain. J Biomech, 2010, 43: 235–241. [Medline] [CrossRef]
24) Peeler J, Anderson JE: Effectiveness of static quadriceps stretching in individuals with patellofemoral joint pain. Clin J Sport Med, 2007, 17: 234–241. [Medline] [CrossRef]
25) Mason M, Keays SL, Newcombe PA: The effect of taping, quadriceps strengthening and stretching prescribed separately or combined on patellofemoral pain. Physiother Res Int, 2011, 16: 109–119. [Medline] [CrossRef]
26) Hilal Z, Killingback A, Robertson C, et al.: The effect of exercise and electrical muscle stimulation on the architecture of the vastus medialis oblique—the 'Empi' electrotherapy system. Glob J Ortho Res, 2018, 1: GJOR.MS.ID.000503.
27) Moseley GL: Do training diaries affect and reflect adherence to home programs? Arthritis Rheum, 2006, 55: 662–664. [Medline] [CrossRef]