



# Open-chain and closed-chain exercise regimes: an ultrasound investigation into the effects of exercise on the architecture of the vastus medialis oblique

Abdel R. Elniel<sup>1†</sup>, Claire Robertson<sup>2†</sup>, Alban Killingback<sup>3†</sup> and Philip J. Addis<sup>1\*</sup>

\*Correspondence: [padds@sgul.ac.uk](mailto:padds@sgul.ac.uk)



<sup>†</sup>These authors contributed equally to this work.

<sup>1</sup>Institute of Medical and Biomedical Education (Anatomy), St. George's, University of London, London, UK.

<sup>2</sup>Wimbledon Clinics, Wimbledon, London, UK.

<sup>3</sup>Department of Medical Physics and Clinical Engineering, St George's Healthcare NHS Trust, London, UK.

## Abstract

**Background:** Recent discussions have compared the use of closed-chain and open-chain kinetic exercises in the management of patellofemoral pain. Literature shows disparity over the preferred method. While the clinical effectiveness of the two different approaches has been compared, there is no information in the literature on the effect of these exercise types on the vasti muscles of the thigh. This study compared the impact of open-chain and closed-chain exercise regimes on the architecture of the vastus medialis oblique.

**Methods:** Vastus medialis oblique architecture was measured using ultrasound in 23 young, asymptomatic volunteers. Matched subjects were then assigned to one of two six-week exercise programmes, using either closed-chain or open-chain kinetic exercises.

**Results:** Both groups showed a significant increase in mean vastus medialis oblique fibre angle, (from 70.27° to 74.5° [Ocke], and 67.5° to 73.0° [Ccke],  $p < 0.001$ ); insertion length (from 21.26 mm to 25.98 mm [Ocke], and 17.05 mm to 22.23 mm [Ccke],  $p < 0.001$ ); and insertion ratio (from 41.0% to 48.46% [Ocke] and 32.0% to 41.57% [Ccke],  $p < 0.001$ ) following 6 weeks of both open-chain and closed-chain exercises. However, no significant difference was found between the two groups.

**Conclusions:** The results of this study suggest that both open-chain and closed-chain exercise regimes have an equal effect on the architecture of the vastus medialis oblique after six weeks of exercise therapy.

**Keywords:** Vastus medialis, exercise therapy, patellofemoral pain, ultrasound

## Introduction

The quadriceps femoris muscle group lies in the anterior thigh, and consists of four separate muscles: rectus femoris, vastus intermedius, vastus medialis (VM) and vastus lateralis (VL). The quadriceps femoris acts as a knee extender, inserting into the quadriceps tendon, which, through its continuation as the *ligamentum patellae*, inserts into the tibial tuberosity. The VM and VL also act to stabilise the patella through their insertions at the patellar margins [1].

Due largely to the angulation of the femur on the tibia (the "Q angle"), the patella tends to displace laterally when the

quadriceps are forcefully contracted. The distal fibres of the VM, attached to the medial border of the patella more distally than those of the VL, help to resist lateral displacement [2,3]. Various cadaveric investigations have found two distinct alignments of the fibres of the VM which have led them to be identified as two distinct muscle portions, the vastus medialis oblique (VMO) and the vastus medialis longus (VML) [4-6]. There is, however, an ongoing controversy over whether the two portions are functionally separate [7-10]. A recent electromyographic investigation by Tenan et al., [11] however, appears to confirm that the VMO and VML are indeed neurologically separate muscles.

Patellofemoral pain is a commonly-presenting condition, usually manifesting as anterior or retro-patellar knee pain, and more common in young, athletic females. Estimates of its prevalence vary from 3% to 40% of the population [12]; a study by Cowan et al., [13] estimated that 20% of the student population are affected. Although the pathogenesis of PFP is generally agreed to be multi-factorial, it is thought that patella maltracking plays a key role [14]. Weakness in the VMO can lead to lateral deviation of the patella, leading to stress on the patella and peripatellar tissue resulting in PFP [15,16]. Although VMO insufficiency has not been shown to be the primary cause of PFP, the current breadth of data supporting VMO involvement in patellofemoral pain has affirmed its significance as a contributing factor. As a consequence, conservative therapy aims to strengthen the quadriceps, and in particular the VMO, via physical therapy [17]. Targeted exercises have been shown to increase the fibre angle and insertion level of the VMO, thereby increasing the medialising effect on the patella of contraction of the VM [18].

There has been discussion as to which type of exercise is more effective: “closed-chain” (where the distal end of the limb is fixed) or “open-chain”, where the distal end of the limb is free to move. Studies have generally shown an improvement in symptoms and improved functionality in PFP sufferers following both OCKE and CCKE exercises, though there have been differing reports as to which was the more effective [19-22]. While there is conflicting evidence as to the relative effectiveness of the two types of exercise, there is no information currently available on the relative effects of OCKE and CCKE on the actual morphology of the VMO.

In this study we used ultrasound – a safe, non-invasive imaging modality, to investigate the fibre angle and insertion level of the VMO in a group of 23 young, asymptomatic male volunteers. Asymptomatic volunteers were chosen in order not to compound the variables with the effects of PFP on the individuals’ ability to carry out the exercises. The application of ultrasound in investigations into skeletal muscle architecture has been demonstrated in multiple studies (e.g., [23,24]). The method used here has been validated [25], and has been used in previous investigations into the VMO [18,26-29].

The purpose of this study was to compare the effects of open-chain and closed-chain kinetic exercises (OCKE and CCKE) on the architecture of the VMO following a six-week exercise programme, in two groups of volunteers. Ultrasound was used to measure the VMO fibre angle and insertion level in the subjects both before and after the exercise programme.

## Methods

### Study design

The participants were split into two equal groups. Each group then undertook a six-week quadriceps training programme using either OCKE or CCKE exercises. The participants were scanned with ultrasound before and after the exercise programme. The VMO fibre angle and insertion level were recorded.

### Participants

Twenty-three young, asymptomatic male volunteers were recruited to take part in this study. The study was approved by the local Ethics Committee, and all subjects gave informed consent prior to the initial examination. Details of the subjects are given in Table 1. The sample size was in line with similar studies in the literature (e.g., [18,22,23]).

Exclusion criteria: volunteers were excluded if they reported any current or previous knee pain, previous knee surgery, quadriceps injury, a Tegner activity score >3, or gym leg training  $\geq$ once a week, or if they had any lower limb deformity or abnormality. The Tegner activity scale is a validated 10-point scale that quantifies an individual’s level of activity [30]. For this study, participants were required to be sedentary (i.e., with a Tegner score below 3), so that any observed changes could be attributed with confidence to the exercise regime. Volunteers who trained regularly at the gym were also excluded, for the same reason (the Tegner scale does not include gym activity).

### Procedure

The ultrasound technique used in this study followed the method that has been validated and described in several previous studies [18,25-29]. Participants were positioned supine on the examination couch; a pillow was placed under the ankles to immobilise the lower limbs. The superior border and apex of the patella were palpated and marked using a skin pen and transparent ruler. Clarke CM145 digital callipers (accurate to 0.01mm) were then used to measure the patella length. The callipers were then used to determine the mid-point of the patella (width divided by 2), which was marked. The femoral axis was then marked by placing a stainless steel metre ruler from the subject’s anterior superior iliac spine (ASIS) to the midpoint of the patella. A line indicating the femoral axis was marked along the patella.

Volunteers underwent an initial ultrasound scan to determine base-line measurements of fibre angle and VMO insertion level with a Philips iU22 ultrasound machine, with 15-7 linear-array probe. In order to eliminate inter-rater vari-

**Table 1. Mean ( $\pm$ SD) anthropometric data of CCKE and OCKE groups.**

	Weight (Kg)	Height (m)	BMI (Kg/m <sup>2</sup> )	Age	Tegner Score
OCKE (n=11)	78.32 ( $\pm$ 14.52)	1.81( $\pm$ 0.072)	23.8 ( $\pm$ 3.2)	20.7 ( $\pm$ 1.35)	2.0 ( $\pm$ 0.99)
CCKE (n=12)	74.03 ( $\pm$ 10.01)	1.78 ( $\pm$ 0.047)	23.39( $\pm$ 3.2)	19.92 ( $\pm$ 1.0)	2.1 ( $\pm$ 0.9)
<b>Total (n=23)</b>	<b>76.08 (<math>\pm</math>12.28)</b>	<b>1.79 (<math>\pm</math>0.06)</b>	<b>23.58 (<math>\pm</math>3.13)</b>	<b>20.3 (<math>\pm</math>1.22)</b>	<b>2.05 (<math>\pm</math>0.94)</b>

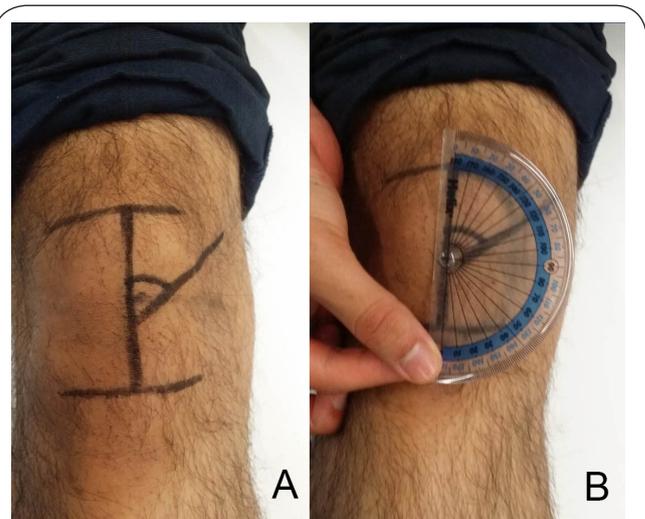
The differences between the means for the two test groups were not significant ( $p>0.05$  in all cases).

ability, the same operator carried out all the scans in this study. Transmission gel was applied, and the probe was placed horizontally on the subject's thigh, just superomedial to the superior patellar border. The probe was moved proximally until a substantial number of VMO muscle fibres could be seen on the monitor. The probe was rotated anti-clockwise for the right knee and clockwise for the left knee, until the fibres appeared parallel to one another. Care was taken to avoid undue applying undue pressure which could distort the underlying soft tissue (**Figure 1**).

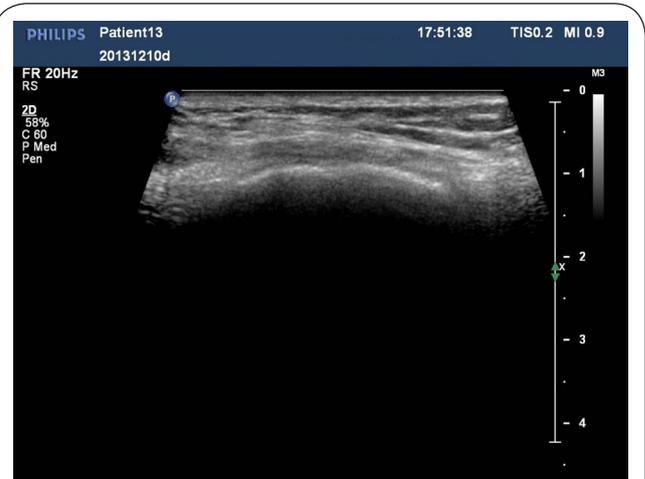
At the point of maximum angle, a screenshot was taken of the image and the ends of the probe were marked on the subject's thigh. The ultrasound gel was wiped from the subject's knee and a line was drawn through the two pen markings, and continued to intersect with the femoral axis. The angle was measured using a protractor (resolution 1°) (**Figure 2**).

The probe was placed horizontally on the thigh once again, just medial to the superior patellar border. With the VMO fibres apparent on the monitor, the probe was tracked distally until the fibres of the VMO were no longer visible. The point at which muscle fibres become no longer visible indicated the end of the muscle's distal attachment (**Figure 3**). This was marked, then the distance between the superior patellar border and marked line was measured using the digital callipers. This measurement represents the insertion length. Dividing this value by the patella length gives the insertion ratio, which can be presented as a percentage.

Participants (matched for height and BMI) were randomly allocated to one of two groups (using an on-line random number generator), and assigned either an open-chain (Ocke) or closed-chain (Ccke) kinetic exercise programme, every other day for six weeks [17,31]. Each group was given a choice of one of two very similar exercises to complete throughout the study. Exercises were chosen that were easy to perform at home, were commonly used in clinical practice, and were



**Figure 2.** (A) The points marked either side of the probe are used to draw a line to the femoral axis; (B) The angle between the two lines is measured using a protractor.



**Figure 3.** Ultrasound image. VMO fibres are no longer visible indicating the distal limit of insertion (compare with **Figure 1** above).



**Figure 1.** Ultrasound image.  
\*Indicates parallel fibres of VMO.

aimed to produce the same effect of light fatigue in both groups [32]. "Fatigue" was described as shaking or a sense of tiring from the muscle as perceived by the subject. All individuals were given an instruction sheet and demonstrations from a specialist Physiotherapist on how to complete the exercises. Participants were asked to complete a diary to monitor compliance.

For the Ocke programme, subjects had a choice of two exercises: supine straight leg raise or supine isometric quadriceps contractions, to be repeated until the first signs of fatigue. The time to reach fatigue was expected to vary between individuals, and to take longer as the study progressed. Exercises were to be carried out on each leg alternately. Data from all limbs were averaged.

For the CCKE regime, the two exercises were:

1. With their hands placed firmly on a stable surface, subjects were asked to stand fully on one leg, with the other leg flexed to 90° at the knee. They then had to squat down to approximately 20° and hold this position for four seconds. They then returned to their initial stance for a four second rest period. This was repeated until the first signs of fatigue. They then swapped legs and repeated the exercise (Figure 4).

2. For this exercise, subjects used a stable surface, no greater than 10cm high, ideally the bottom step of a set of stairs or a small step ladder. With one leg on the step, subjects were asked to slowly lower themselves until the other leg just touched the floor and then return to the start position. Subjects were asked to focus on using the muscles in the anterior thigh to control the descent. This exercise was completed until patients felt the initial signs of fatigue; once completed they were asked to swap legs and repeat (Figure 5).

On completion of the six-week exercise programme, subjects were re-scanned. The patella was re-measured to provide an assessment of operator reliability.

### Statistical analysis

Statistical analysis was carried out using SPSS v24.0 (IBM SPSS

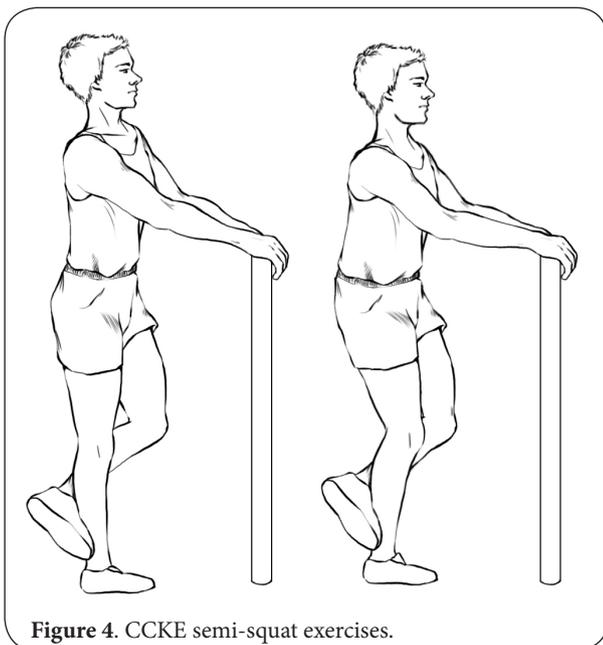


Figure 4. CCKE semi-squat exercises.

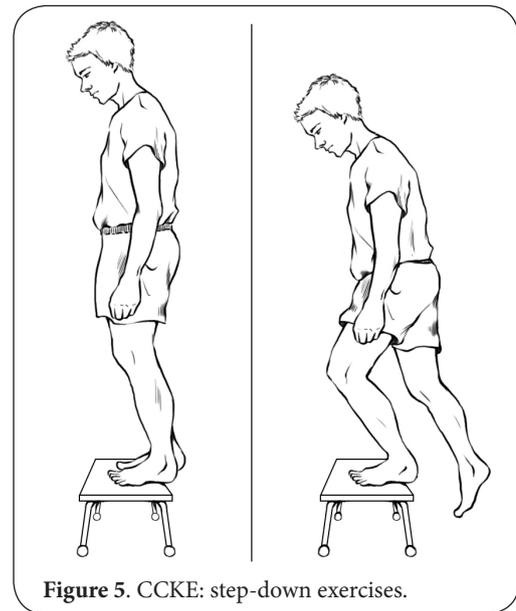


Figure 5. CCKE: step-down exercises.

Statistics). An independent sample t-test was used to compare the means of the baseline data for the two test groups, and the changes in VMO fibre angle, insertion length and insertion ratio for OCKE versus CCKE following exercise. A paired t-test was used to evaluate significant changes, before and after intervention. A P-value of less than 0.05 was taken to denote significance. The correlation coefficient was used to test correlation between initial values and the amount of change after intervention. For the test-retest reliability assessment, Pearson’s correlation coefficient for the two sets of patella length measurements was calculated.

### Results

Twenty-three male volunteer took part in the study. Anthropometric data for the participants are summarised above (Table 1). There were found to be no significant differences between the means of the baseline values for the two experimental groups ( $p > 0.05$ ). Both groups showed a significant increase in VMO fibre angle after exercise ( $p < 0.001$ ). A mean VMO angle change of  $4.65^\circ (\pm 3.36)$  was observed in the OCKE group. The CCKE-only group showed a mean change of  $5.73^\circ (\pm 2.87)$ . The difference in mean angle change between the two groups was not significant ( $p = 0.31$ ) (Table 2).

A mean increase in insertion length (i.e., the length of VMO inserted onto the patella) of  $4.31\text{mm} (\pm 5.33)$  was seen

Table 2. Mean ( $\pm$ SD) VMO fibre angle, insertion length and insertion ratio before and after exercise programme.

	OCKE			CCKE			P-value OCKE vs CCKE
	Initial (mean)	Post-exercise (mean)	Change	Initial (mean)	Post-exercise (mean)	Change	
Fibre angle ( $^\circ$ )	70.27 ( $\pm 8.43$ )	74.5 ( $\pm 6.66$ )	4.65 $\pm$ 3.36	67.5 ( $\pm 7.85$ )	73.0 ( $\pm 4.85$ )	5.73 ( $\pm 2.87$ )	0.31
Insertion length (mm)	21.26 ( $\pm 4.78$ )	25.98 ( $\pm 4.59$ )	4.31 $\pm$ 5.33	17.05 ( $\pm 5.47$ )	22.23 ( $\pm 5.91$ )	4.63 ( $\pm 2.92$ )	0.82
Insertion ratio (%)	41.0 ( $\pm 9.0$ )	48.46 ( $\pm 7.84$ )	6.15 $\pm$ 9.89	32.0 ( $\pm 10.0$ )	41.57 ( $\pm 10.51$ )	7.97 ( $\pm 4.91$ )	0.48

in the OCKE group. In the CCKE group the mean increase was 4.63 mm ( $\pm 2.92$ ) ( $p < 0.001$ ). No significant difference was observed between the two interventions ( $p = 0.82$ ) (Table 2).

The mean increase in insertion ratio (i.e., the insertion length expressed as a percentage of patella length) in the OCKE group was 6.15% ( $\pm 9.89$ ). In the CCKE group, the mean increase was 7.97% ( $\pm 4.91$ ) ( $p < 0.001$ ). No significant difference was observed between the two interventions ( $p = 0.48$ ) (Table 2).

There appeared to be little correlation between fibre angle change and insertion length change ( $R^2 = 0.0606$ ); some participants showed a significant change in insertion length without a substantial increase in VMO fibre angle and *vice versa*.

There was an observable inverse relationship across all participants in the study, between initial fibre angle and fibre angle change, where by individuals with a smaller initial fibre angle showed the greatest amount of angle change following the exercise regime ( $R^2 = -0.59$ ). Similarly, individuals with a smaller initial insertion length showed a greater change following exercise, though the correlation was less marked ( $R^2 = -0.17$ ).

The mean self-reported compliance was 67% ( $\pm 3.36$ ) in the OCKE group, and 68% ( $\pm 2.87$ ) in the CCKE group.

### Test-retest reliability assessment

The coefficient of correlation for the two sets of patella length measurements was 0.86, indicating good reliability.

### Discussion

This study was designed to investigate the effect of open and closed-chain kinetic exercises on VMO architecture. There is a disparity in the literature regarding the relative merits of OCKE and CCKE in treatment of PFP. Studies have shown there to be a significant improvement in functionality in symptomatic PFP patients following both treatments, with most authors favouring CCKE [19-21,31]. What has not been available hitherto, however, is evidence of whether, and to what extent, these treatments can lead to observable differences in the architecture of the VMO.

The exercises chosen for this study were adapted from those used in previous studies on OCKE and CCKE [18,32,33]. It was thought that compliance would be improved if participants could choose their preferred exercise, so they were allowed to choose from two exercises throughout the six week period.

Escamilla et al., [34] studied the biomechanics of the knee during CCKE squats and leg presses, and OCKE leg extensions. They reported that CCKE recruited more muscle groups and was shown to be more effective at employing the vasti muscles. OCKE, however, produced greater rectus femoris activity, and they therefore concluded that OCKE may be more effective than CCKE at overall quadriceps development.

We found very little difference in mean angle change between the OCKE and CCKE exercise programmes. Although the CCKE group achieved a slightly greater average increase (4.65° compared to 5.73°), the difference was not statistically

significant ( $p = 0.31$ ). While increases in fibre angle following resistance training are to be expected in pennate muscles [35-37], no previous studies have investigated the architecture of the vasti muscles following these two interventions. From a clinical perspective, the results suggest that preference for semi-squat exercises over straight leg raises may be misplaced. This was founded upon the idea that CCKE would have greater impact on the VM, and was supported by increased thigh circumference in the CCKE study group [33].

Of course, CCKE may have more impact on PFPS than simply by strengthening vastus medialis: Petersen et al., [14] outline the role of hip abductors, hamstring muscles and the lower back in patellar stress; Escamilla et al., [34] observed twice as much hamstring activity in squat exercises compared to leg extensions. Squat exercises also involve core and back muscle to stabilise the body on descent. The multi-target nature of such a CCKE regimen may therefore bring more benefits to PFPS patients than just strengthening the VMO.

Witvrouw et al. [21], however, found long-term outcomes equally good following both types of exercise. Based upon these findings, it may be that combined OCKE and CCKE therapy would be most effective. The results reported here tend to support this.

A negative correlation was observed between initial angle and degree of angle change ( $R^2 = -0.59$ ), such that participants with a smaller initial angle saw greater angle change compared to those with larger initial angles. Jan et al., [27] reported smaller VMO fibre angle in PFPS patients relative to controls, though there is wide variation. The findings reported here tend to support the suggestion by Khoshkhoo et al., [18] that a simple ultrasound screening test could be employed in clinic to identify patients with a low initial fibre angle, for whom VMO strengthening exercises might be most effective.

There was a mean insertion length increase of 4.31mm ( $\pm 5.33$ ) in the OCKE group and 4.63mm ( $\pm 2.92$ ) in the CCKE group. While both studies showed significant increases, there was no significant difference between the exercise types ( $p = 0.82$ ). Increased insertion length is a phenomenon often associated with an increase in muscle volume [27], which is supported by the results reported here. A weak inverse relationship was noted between initial insertion length and insertion length change ( $R^2 = -0.17$ ), which echoes the relationship seen in fibre angle change. The mean insertion ratio (i.e., insertion length/patella length expressed as a percentage) increased by 6.15%  $\pm 9.89$  in the OCKE group, and by 7.97%  $\pm 4.91$  in the CCKE group. There was no significance between the two groups ( $p = 0.48$ ).

A study by Benjafeld et al., [29] found an average insertion ratio of 43.0% in athletic individuals, compared to 39.5% in sedentary individuals (the overall initial ratio in our study was 36.83%, which supports the low Tegner scores reported by the participants). The increase in insertion length, and hence increased ratio, following the exercise programme, enables a greater medial pull on the patella by the VMO, facilitating

correction of the lateral tilt and shift often seen in PFPs.

It is important to consider the level of compliance in a study of this type. The OCKE group had an average self-reported compliance of 67% compared to 68% amongst the CCKE group. Although both are closely similar, the standard deviation in the CCKE group (2.87) was smaller than the OCKE group (3.36), signifying greater consistency, which may have influenced the outcome of the exercises.

Despite the reported validity of the *in vivo* ultrasound method [25], there may be a degree of subjectivity in interpretation of the ultrasound image. The reliability of the results was enhanced by having all the measurements taken by the same investigator throughout the study. The test-retest results for this observer showed a high level of reliability. While the cohort size of twenty-three individuals is comparable to other studies in the literature, a larger sample size would have strengthened the study, particularly in view of the relatively large standard deviation seen in some of the data.

## Conclusions

Both OCKE and CCKE exercise regimes brought about significant changes in the muscle architecture of the study subjects following six weeks of exercise; however, the difference between the two groups was not significant. We can conclude, therefore, that the difference between the effects of OCKE and CCKE regimes was insignificant in all the parameters of VMO morphology investigated here, and that in terms of bringing about a measureable change in the fibre angle, insertion level, and insertion ratio of the VMO, both types of exercise are equally effective.

## List of abbreviations

CCKE: Closed-chain kinetic exercise

OCKE: Open-chain kinetic exercise

PFP: Patellofemoral pain

VL: Vastus lateralis

VM: Vastus medialis

VML: Vastus medialis longus

VMO: Vastus medialis oblique

## Competing interests

The authors declare that they have no competing interests.

## Authors' contributions

Authors' contributions	ARE	CR	AK	PJA
Research concept and design	--	✓	--	--
Collection and/or assembly of data	✓	--	✓	--
Data analysis and interpretation	✓	✓	✓	✓
Writing the article	✓	✓		✓
Critical revision of the article	✓	✓	✓	✓
Final approval of article	✓	✓	✓	✓
Statistical analysis	--	--	✓	✓

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