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How Does a Standing Exercise Programme Focusing on Hip-Abduction Strength Affect Anterior Knee Pain in Runners?

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Abstract

Outline: *Anterior Knee Pain (AKP) is the most prevalent injury in running. Growing evidence suggests that hip muscle imbalance plays a role in the development of AKP. Gluteus Medius (GMed) is the main abductor of the hip and also stabilises the pelvis during gait. Studies show that hip-abduction strength is decreased in populations with AKP. This relates to increased hip-adduction, hip internal rotation and knee abduction, which are associated with higher patellofemoral contact pressures.* ***Objective:*** *The main aim of this study is to determine whether a standing exercise programme will improve hip-abductor strength. The second aim of the study is to determine whether there will be a decrease in running-related pain after completing a six-week standing exercise programme.*

Design: *Within-participant pre-test/post-test comparative trial.*

Setting: *The Sport's Clinic at the Malta Football Association. Ta Qali National Stadium (Malta).*

Main outcome measures: *GMed torque was measured using a Biodex® System 3 isokinetic dynamometer as demonstrated by Brent et al (2013). The Numerical Rating Scale was used to measure pain related to running.*

Results: *Pre-test torque scores were higher on the affected side. Scores on the affected side improved by 22.81% from a mean baseline average of 96.00Nm/kg to 117.86Nm/kg, (p-value 0.013). Scores on the unaffected side improved by 27.97% from a mean baseline average of 90.14Nm/kg to 115.29Nm/kg (p-value 0.031). Post-test scores were more balanced between limbs. Pain scores decreased from 5.29 as measured on the NRS to 1.00 (p-value 0.000).*

Conclusion: *Standing exercises aimed at strengthening the hip-abductors may prove to be a valid intervention for prevention and rehabilitation of AKP. However, better quality studies are needed in order to validate this.*

Keywords

Gluteus Medius, Knee Pain, running, exercise

1. Introduction

Running has gained in popularity over the years. It is a good way to keep fit and is easy for most people to do and tailor to individual needs. However, it has been found that the more hours spent running the higher the incidence of injury and that the most common site of running injury is the anterior knee (Hespanhol et al., 2011; Chang et al., 2012; van Poppel et al., 2014). Anterior Knee Pain (AKP) is a non-specific diagnosis given to patellofemoral joint disorders, which are known to be developmentally multifactorial (Nijs et al., 2006). The title AKP is synonymous with Patellofemoral Pain Syndrome (PFPS) with both terms frequently cited in the literature. It has been stated that females suffer the incidence of running-related AKP twice as often as their male counterparts (Boling et al., 2010). Saragiotto et al. (2014) contradicted this, as they could find no valid evidence in a systematic review investigating risk factors for running injuries, except for previous injury. However, another systematic review by Lankhorst et al. (2015) found the only risk factors that may be valid for AKP are decreased knee extensor strength and being female. Recent studies imply that imbalance of hip muscles play a role in the development of AKP (Bourghuis et al., 2008) and that intervention aimed at hip strengthening may be preventive or useful for rehabilitation (Earl & Hoch, 2011; Ferber et al., 2011).

1.1 Gender Issues

The relationship between hip-abductor strength and control of knee-abduction (valgus) has been repeatedly cited in the literature (Brent et al., 2013). This is especially relevant in sport where females often land in a valgus position when jumping and have increased dynamic valgus during directional changes than males. Historically it has been thought that the greater Q-angle determined by the width of the female pelvis in relation to the patella may be a risk factor. Livingston and Mandingo (1999) disputed this and noted that imbalance between the two sides was a more relevant problem. Park and Stefanyshyn (2010) undertook an experimental study on males and females and found that a greater Q-angle does not correlate to increased knee-abduction, which has been related to AKP during running (Stefanyshyn et al., 2006).

Several studies have been conducted which have found evidence that females run with greater peak Gluteus Maximus (GMax) activation (Souza & powers, 2009, Barton et al., 2013) which may lead to earlier fatigue and predispose to injury (Willson et al., 2012). While GMax extends and laterally rotates the hip, Gluteus Medius (GMed) abducts the hip and stabilises the pelvis (O’Dwyer et al., 2011). The stability role of GMed is essential to prevent pelvic drop during the swing phase in the gait cycle as it controls the frontal plane during ambulation and is more active in running than in walking (Klemetti et al., 2014). An EMG study conducted by Willson et al. (2011) found that GMed activation was delayed and of shorter duration in females with knee pain compared to controls. However they found no difference in GMax timing or activation between the two groups. It is important to consider at this point that if there were decreased GMed activity there would be less control of pelvic drop during single-leg stance, which would facilitate femoral-adduction and knee-abduction. This is in effect, a dynamic rather than a static Q-angle, which may be related to AKP as evidenced by Khayambashi et al.

(2012).

Brent et al. (2013) conducted a well-designed prospective study which noted a significant increase in adolescent male hip-abduction strength as the subjects matured that was not matched in adolescent females. They related their findings to increased incidence of ACL injury in female athletes compared to males. Also, de Marche Baldon et al. (2011) investigated the difference in hip-abductor torque between the genders. They found that females had weaker hip-abductor torque, increased contralateral pelvic depression, femoral-adduction and knee-abduction than the males. In this case torque is the rotational force generated when the thigh pushes the lever arm of an isokinetic dynamometer laterally. It was additionally noted that females who exhibited greater torque also displayed better control of the kinetic chain. So although static Q-angle may not be correlated to AKP in athletes it appears that decreased hip-abductor strength may be related to muscle imbalance, abnormal biomechanics and increased patellofemoral stress (Robinson & Nee, 2007; Noehren et al., 2012). This would be especially relevant with repetitive limb loading such as found in running. Some studies have shown that increased patellofemoral stress and chondral defects may not be related to AKP (Flanigan et al., 2010) but an MRI study by Islam et al. (2015) demonstrated that subjects with PFPS had higher patellofemoral contact stress than controls.

1.2 Muscle Imbalance

Powers (2010) conducted a comprehensive overview of the problem and concluded that there is growing evidence that proximal muscle imbalance is implicated in the development of AKP. Dierks et al. (2008) conducted a controlled study testing hip-abduction and hip-external rotation strength before and after a long run. They found that the PFPS group displayed significantly lower hip-abduction strength and increased peak hip-adduction angles which both became more pronounced by the end of the run. These findings are consistent with the theory that muscle imbalance at the hip will facilitate increased hip-internal rotation and hip-adduction and associated increased tibial-abduction and/or external rotation (Willson & Davies, 2008; Paoloni et al., 2010) during running. This may elevate patellofemoral contact pressures as mentioned (Lee et al., 2003). This is supported by Lee et al. (2001) who conducted a cadaveric study finding that knee flexion angles of 30° and 60°, correlating to running angles, relate to increased tibial torsion and patellofemoral contact pressures.

It has to be mentioned that the Vastus Medialis Obliquus (VMO) muscle has also been implicated as a correlative factor to AKP and has been the main focus of physiotherapeutic intervention. Interestingly an animal study undertaken by Sawatsky et al. (2012) found that ablating VMO made no difference to patella contact pressures at varying degrees of knee flexion. They call into question the theory that VMO weakness is causative of AKP although it may be an effect due to reflex inhibition (Ott et al., 2011). It is often stated that both GMed and VMO are affected in patients with AKP but recent studies investigating EMG activity of the GMed and VMO have found that symptomatic limbs of subjects with AKP have delayed onset of GMed but not of the VMO (Bolgla et al., 2011). Although VMO onset was not found to be delayed in AKP (Brindle et al., 2003; Cavazzuti et al., 2010), shorter muscle impulse duration of both GMed and VMO activity has been reported by Aminaka et al. (2011), which may be due to pain inhibition. However, Barton et al. (2013) found that delayed and shorter impulse GMed EMG readings may indicate that lack of control of the hip muscles may be predicative of AKP development. Prospective studies conducted by Finoff et al. (2012) and Thijs et al. (2012) found that participants who developed AKP during a running season lost hip-abductor and hip-external rotation strength when they compared pre and post injury dynamometry which suggests that hip muscle weakness is an effect of AKP. This is interesting as the hip-abductors and external rotators are implicated as both cause and effect.

More investigations are needed into which interventions will target activation patterns that would be the most effective in prevention and rehabilitation of this condition. Considering the current evidence, it is hypothesised that re-educating the proximal stabilising muscles to optimise control of the kinetic chain will improve dynamic alignment while running and subsequently decrease pain. Although anecdotally specific exercises are lauded, and have become almost compulsory "best-practice" for prevention and cure, few studies investigating exercise protocols and their effects on AKP in running have been undertaken. Fukuda et al. (2010) conducted a study of sedentary females with AKP dividing participants into 3 groups: no treatment, knee strengthening and hip and knee strengthening. They found that strengthening the hip and knee musculature was better than strengthening the knee alone and both exercise groups had better outcomes with regard to pain and function than no treatment at all. If increased hip-adduction, hip-internal rotation and knee-abduction cause increased stresses to the knee it may be proposed that a higher hip external-to-internal rotation strength ratio may protect against symptoms during running by reducing valgus forces on the knee.

Powers (2010) suggests improving trunk and pelvic control in relation to the biomechanics of the hip and knee during sporting activities. In view of the evidence pointing to hip-abductor weakness being related to AKP in running, especially as the runner begins to tire, it seems possible that strengthening these muscles may be beneficial. Exercises in standing may have a better effect than mat-based exercises as they are more functional (Boling et al., 2006; Saeterbakken & Fimland, 2011; Abdel-aziem et al., 2013), address balance (Coquiero et al., 2005) and proprioception (Ashton-Miller et al., 2001) and may lead to better control from higher centres (Borghuis et al., 2008).

1.3 Aims of the Study

The first aim of this study is to determine whether a standing exercise programme designed for runners will improve hip-abductor strength. The second aim is to determine whether the standing exercise programme has any effect on the symptoms of AKP while running.

2. Methods

2.1 Participants

Middle-long distance runners with AKP were recruited through a poster campaign targeting gyms and running clubs in Malta. Applicants were evaluated and accepted to the study based on the inclusion/exclusion criteria related to diagnostic parameters of AKP (Cook et al., 2010) and a physical assessment by a sports physiotherapist. Participants were accepted with a minimal score of four out of ten on the pain scale while doing their usual run, which had to be present for a minimum of six months. Nine participants completed a six-week programme of standing exercises while keeping a running-related pain diary. GMed strength was measured with an isokinetic dynamometer at baseline and on completion of the programme. Nine athletes completed the programme. Six participants were male and three female with an average age of 32.77 (+/- 11) years, average height of 172.22cm (+/- 13.78cm) and average weight 74.88kg (+/- 15.12kg). Two participants had less than 40% exercise compliance so were not included in the final analysis. All participants signed informed consent approved by the Research Ethics Approval Committee for Health at the University of Bath. Data protection was assured.

2.2 Design

A within-participant pre-test/post-test comparative trial was undertaken.

2.3 Setting

The Sport's Clinic at the Malta Football Association. Ta Qali National Stadium (Malta).

2.4 Hip-Abductor Torque Testing Procedure

The Biodex System 3 Isokinetic Dynamometer (Biodex Medical Systems Inc, Shirley, NY) has been proven to be a valid and reliable tool to measure torque (Drouin et al., 2004). A protocol similar to that described by Brent et al. (2013) was used to measure concentric hip-abductor torque in standing (Figure 1). The hip was in a neutral position for testing and the dynamometer resistance pad was placed on the lateral aspect of the femur at two centimetres proximally in relation to the superior pole of the patella and secured with a Velcro strap. The dynamometer rotation axis was aligned medially and to equal height of the anterior superior iliac spine of the pelvis. Participants were instructed to stand straight, facing the dynamometer and to hold on with both hands for support during the procedure. They were instructed to push laterally against the lever arm while maintaining their pelvis and hip in as neutral a position as possible. They performed three submaximal practice repetitions in order to familiarise themselves with the task then took a two minute break before performing three maximal repetitions with a 30-second recovery time between each manoeuvre. Pre-testing was carried out within one week before the start of the intervention and post-testing within one week after completion of the programme.

Figure 1. Isokinetic Test for Hip-Abduction

2.5 Intervention

An exercise programme (Table 1) was utilised that has been developed for runners (Contreras, 2013) and is performed in the upright position which has been deemed more effective for facilitating activity of the hip muscles (Abdel-aziem et al., 2013). The programme consists of 10 exercises that were taught by a sports physiotherapist who has been trained to teach these specific exercises using the modified Pilates method (Withers, E. & Withers, G., 2011). Each participant was coached individually until the physiotherapist was satisfied with technique. They were then given a detailed exercise sheet for each exercise and a six-week diary to record exercise compliance, running activity and pain levels in relation to running. The participants were followed up a week later to consolidate technique and monitor progress. At this time if the exercises were found to be too easy exercise bands were given that were appropriate to the individual's ability. Participants were encouraged to run as usual. They were also asked to refrain from therapeutic intervention for the duration of the programme.

Table 1. Standing Exercise Programme for Runners

Exercise	Description
Calf Raise	Stand with feet hip width apart, pelvis neutral and hands on top of pelvis. Shift weight onto balls of the feet and lift heels off the floor. Lower slowly. 20 repetitions.
Semi Squat	Stand as above. Bend knees to 45°-60° as though sitting, tipping upper body forward. Keep knees in line with second toe. Straighten up. 20 repetitions.
Foot Series	Perform Semi Squat. Hold. Lift heels off floor. Straighten knees to calf raise position. Lower slowly. Repeat 10x. Repeat in reverse sequence 10x
Single Leg Squat	As for Semi Squat. On one leg. Pelvis neutral throughout. 20 repetitions each leg.
Single Leg Calf Raise	As for Calf Raise. On one leg. Pelvis neutral. May need support. 20 repetitions each leg.
Lunge	Split stance, feet hip width apart. Front foot flat, back foot on toes. Bend knees so that back knee lowers toward floor and front knee does not cover toes. Keep hips, knees, feet aligned. Straighten by pressing front heel into floor. 10 repetitions each leg.
Lunge Thrust	Start slightly lower to above. Arm forward opposite to front leg. Shift weight onto front leg and drive opposite knee to ceiling. Drive opposite arm forward. Keep neutral pelvis/spine. 10 repetitions each leg.
Resisted Side Squat	Tie resistance band around both ankles. Stance limb in Semi squat. Abduct non-weight bearing limb away from mid-line. Return to start position. Right and left alternate. 10 repetitions.
Skater Squat	Single leg stance. Other leg extended, toes lightly touching floor. Lower front leg to Semi Squat while reaching non-weight bearing limb in a posteromedial direction with toes skimming the floor. Return to start position. 10 repetitions each leg.
Jump and Land	Feet hip width apart. Lower to Semi/Full Squat. Extend knees, hips, feet while swinging arms forward. Land with gentle Semi Squat in correct alignment. 10 repetitions.

The Numerical Rating Scale has been found to be valid, reliable and an easier tool to measure pain intensity (Hawker et al., 2011; Hjermstad et al., 2011) than the Visual Analogue Scale. It was included on the running/pain diary for convenience (Figure 2). Participants were asked to fill the diary daily, noting duration of run, pain scores and if pain interfered with the run. A separate sheet was given for exercise compliance.

Rating	Pain Level
0	No Pain.
1-3	Mild Pain (nagging, annoying, interfering little with run).
4-6	Moderate Pain (interferes significantly with run).
7-10	Severe Pain (disabling, unable to run).

Pain Diary-. Write Pain Rating in the shaded box. Write how long it took for pain to come on and if it stops the run in the white box.

Week	Sunday		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Comments
1															
2															
3															
4															
5															
6															

Figure 2. Running/Pain Diary with NRS

2.6 Statistical Analyses

Statistical mean values and standard deviations were calculated for each variable. Analysis of variance on the dependant variables of hip-abductor torque and running-related pain were related to the independent variable of time. Hip-abduction torque was measured in Newton-metres (Nm) and normalised to body mass. Paired t-tests were used to compare the results of the dependent variables before and after a six-week exercise programme. Statistical analysis was performed with SPSS (version 21; SPSS Inc, Chicago. IL).

3. Results

Contrary to expectations 57.14% of participants had higher hip-abductor torque (Nm/kg) on the affected side than the unaffected side at baseline (Figure 3). Correlation coefficients of the pre-test and post-test scores were calculated at 0.918 on the affected side and 0.712 on the unaffected side allowing a 95% level of confidence.

Post-test scores on the affected side improved by 22.81% from a mean baseline average of 96.00Nm/kg to 117.86Nm/kg (p-value 0.013). Post-test scores on the unaffected side improved by 27.97% from a mean baseline average of 90.14Nm/kg to 115.29Nm/kg (p-value 0.031). Results were valid with a 5% level of significance. The mean average score on the affected side was 6.15% higher than the unaffected side at baseline but was only 2.25% higher at post-test. Therefore, post-test scores between affected/unaffected limbs were more symmetrical than baseline scores (Figure 4).

Post-test NRS mean average scores decreased from a baseline of 5.29 to 1.00 at post-test, which is an improvement of 81.10% (Figure 5). The correlation coefficient between pre and post-test variables was 0.502. The difference between pre and post-test scores was significant at the 5% level (p-value 0.000).

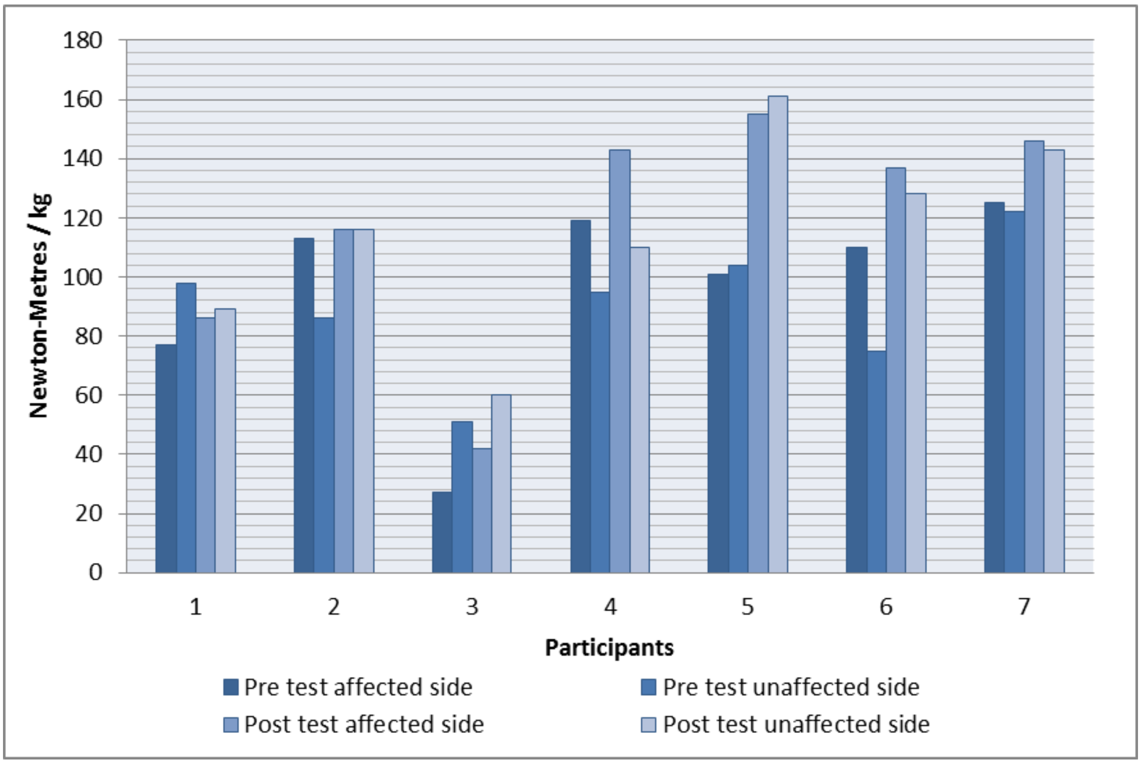

Figure 3. Pre-Test/Post-Test Hip-Abductor Torque (Nm/kg) Results

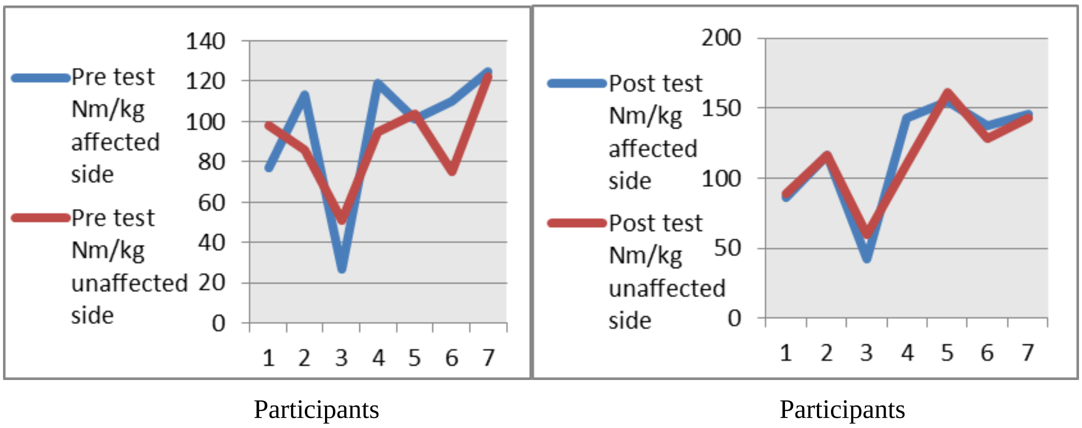

Figure 4. Graphical Representation of Pre-Test and Post-Test Scores of Hip-Abductor Torque

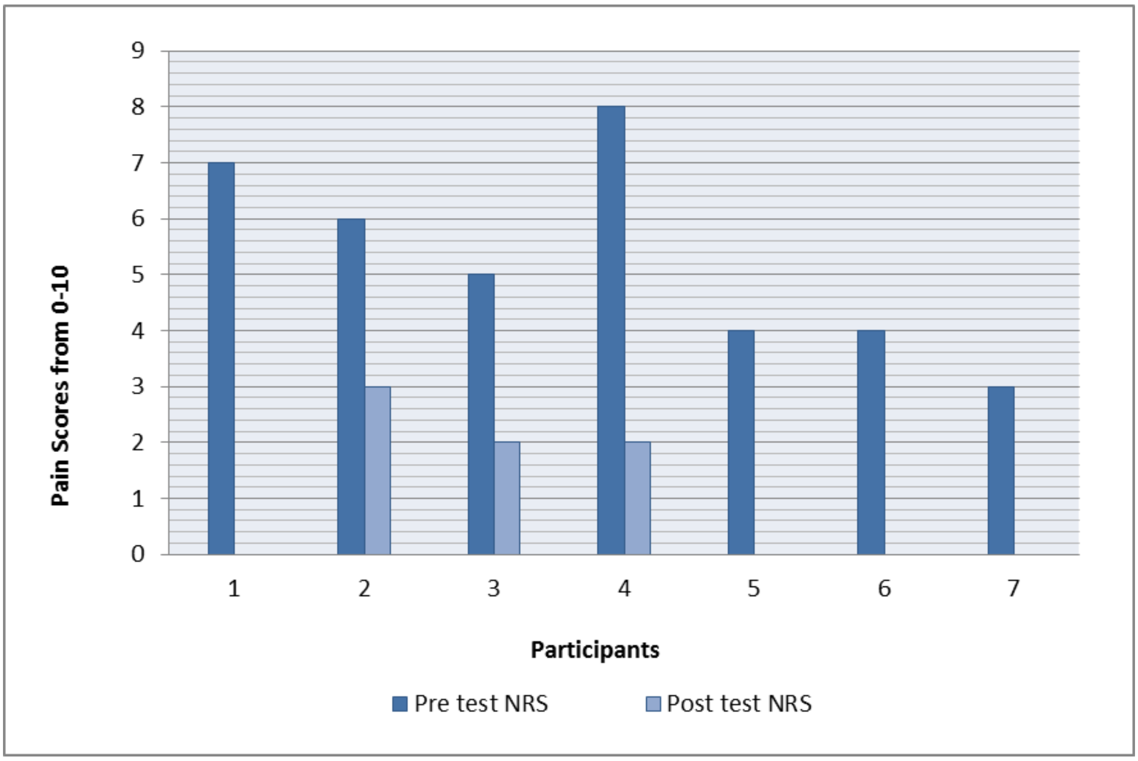

Figure 5. Pre-Test/Post-Test NRS Scores

4. Discussion

The aims of this study were to assess the effects of a standing exercise programme in relation to hip-abductor strength and running-related AKP. The first hypothesis was supported as 13 of the 14 limbs that were tested increased in hip-abductor strength. Pre-test/post-test scores showed an overall improvement of torque from a mean average of 93.07Nm/kg to 116.57Nm/kg. Although pre-test hip-abductor torque scores showed that four of the seven participant's hip-abductors were stronger on the affected side, this became less pronounced at post-test. The final mean average hip-abductor torque difference between the affected and unaffected limbs improved by 43.85% as being 5.86Nm/kg higher on the affected leg at baseline to being 2.57Nm/kg higher on the affected limb at post-test. The second hypothesis was also supported as running-related pain scores decreased by 81.10%.

Good quality, dynamic and sport specific exercise has been deemed the best intervention for AKP by many authors (Nakagawa et al., 2011; Ortiz & Micheo, 2011; Willy & Davis, 2011). The exercise programme used in this study is based on the Pilates principles, which focus on good posture, re-educating the core muscles, and optimal quality of movement, which is synchronised with the correct breathing technique. Carvalho Barbosa et al. (2013) undertook an EMG study looking at Biceps Brachii and upper Rectus Abdominus muscle recruitment and found immediate improvement when the Pilates centring technique was applied. The exercises used in this study come from a "Performance Pilates" programme incorporating strength and conditioning training with movement patterns specific to running (Contreras, 2013). It seems that the added attention paid to detail with this type of exercise leads to specific neuromuscular retraining (Chuter & Janse de Jonge, 2012; Wouters et al., 2012), better co-ordination and so improved muscle recruitment which may be useful for prevention and rehabilitation purposes. Although the aim was to strengthen the hip-abductors in a functional standing position it was decided to use a programme designed for runners that is dynamic, specific and addresses the kinetic chain. Also, the Pilates method commands daily practice, which has been supported for optimal outcomes in recent systematic reviews (Harvie et al., 2011; Clijsen et al., 2014).

It is usual practice to undertake comprehensive testing in order to assess dysfunction and direct treatment appropriately for best outcomes (Grimaldi, 2011). Willy et al. (2012) suggested that "sex-specific" exercise programmes would be more effective than routine strengthening. This would address the fact that females have lower peak-abduction torques relative to mass than their male counterparts. However, gender differences were not taken into account in this study and the possibility that the GMed would be stronger on the affected side had not been envisioned. The exercise programme used in this study focused on good technique and whole body balance while the exercises chosen were also aimed at strengthening the hip-abductors in standing. GMed torque increased bilaterally as expected but it was interesting to find that the unaffected limbs had weaker hip-abductors at baseline and improved more than the affected limbs over the six-week programme leading to better muscle balance.

4.1 Limitations

A limitation of this study was the low number of participants who completed the six-week programme. Another limitation was the lack of a control group. However, as the participants had been suffering AKP for a minimum of six months it could be said that the pre-test results could be treated as a "control" as AKP had been present for longer than the six-week trial. The unaffected limb could also be a substitute for the control group. The results of this study were also affected by the fact that there were only three female participants out of the nine and that two of the females had low compliance and so were not included in the final analysis. Also the foot was ignored in this study. There is evidence pointing to distal factors being related to AKP (Barwick et al., 2012; Collins et al., 2012). As discussed, the whole kinetic chain was addressed during intervention but the scope of this project did not include any parameters to investigate distal causes of AKP. If there were evidence that any participant's main problem was from the foot they would not have been included in this study.

5. Conclusion

Standing exercises aimed at strengthening the hip-abductors may be useful in the prevention and treatment of AKP. The sample in this study is too small to draw any conclusions but the results suggest that further investigations into the relationship between hip-abductor strength and knee function during running would be worthwhile. A good quality prospective randomised controlled trial, including EMG and isokinetic testing would be ideal to assess if an exercise protocol could decrease risk of injury or be optimal for rehabilitation for runners with AKP. Khayambashi et al. (2012) found that decreases in pain were sustained after an eight-week exercise programme for AKP at six months follow-up. However, they did not measure strength at the follow-up which may be predictive of future recurrence. It would be important to conduct a review of outcomes at six and twelve month intervals in order to determine long-term effects of the programme. In a previous study by the author it was found that participants who had been taught Pilates-based exercises had lower pain scores at a six month follow-up than at six-weeks post-intervention (Schembri et al., 2014).

Standing exercises aimed at strengthening the hip-abductors may prove to be a valid intervention for prevention and rehabilitation of AKP. However, a bigger controlled study with three groups, one doing traditional hip-abductor exercises, one doing standing exercises and a control group would be necessary to present a more valid case for standing exercises for running-related AKP.

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