Comparison of pelvic tilt before and after hip flexor stretching in healthy adults

Abstract

Objectives: An increase in anterior pelvic tilt is often assumed to result from short hip flexor muscles. Such altered postural alignment may increase the stress on the lumbar spine and has been shown to be a characteristic of specific low back pain populations. However, there has been minimal research investigating the link between hip flexor muscle length and pelvic inclination/lumbar lordosis in relaxed standing. Therefore, this study sought to understand whether hip flexor stretching would reduce pelvic tilt and/or lumbar lordosis.

Methods: We quantified pelvic tilt and lumbar lordosis before and after a single session of passive hip flexor stretching in a sample of 23 male subjects. Changes in hip flexor length were also characterised, using a Thomas test protocol to measure passive hip extension in supine lying. We investigated both the mean effect of the stretching protocol and potential correlations between changes in passive hip extension and changes in pelvic tilt/lumbar lordosis.

Results: Following the stretching protocol, there was a mean increase of 2.6° ($p<0.001$) in passive hip extension and corresponding mean reduction of 1.2° ($p<0.001$) in anterior pelvic tilt. However, there was no change in lumbar lordosis nor were there any meaningful correlations between the change in passive hip extension and change in pelvic tilt/lumbar lordosis.

Conclusions: The results suggest that hip muscle stretching may lead to immediate reductions in pelvic tilt during relaxed standing. Such stretching programmes could play an important role in interventions designed to improve standing postural alignment.

Keywords

Pelvic tilt; hip flexor; stretching; iliopsoas; lumbar lordosis

Introduction

There is an intrinsic relationship between pelvic orientation in the sagittal plane (commonly referred to as pelvic tilt) and the sagittal profile of the spine[1,2]. Most notable is the reciprocal relationship between lumbar lordosis and pelvic tilt[3], in which increases in pelvic tilt are associated with increases in lumbar lordosis. Importantly, certain clinical back pain populations, such as people with spondylolysis and isthmic spondylolisthesis demonstrate increased pelvic tilt[4] and increased lumbar lordosis[5] in standing. It is therefore essential to develop a clear understanding of the factors which determine pelvic tilt and lumbar lordosis.

Several muscle-related factors have been proposed to influence pelvic tilt in relaxed standing. Importantly, although strength-related factors are often targeted in rehabilitation programmes designed to improve posture[6], research has not shown a clear relationship between maximum torque of either the abdominal or lumbar extensor muscles and pelvic orientation in standing[7]. Given this finding, it likely that passive stiffness or musculotendon length, rather than maximal muscle strength, may be a stronger determinant of pelvic orientation in relaxed standing, when muscle activation is relatively low. In line with this idea, it has been suggested that short hip flexor muscles, such as iliacus or psoas, may exert an increased anterior tilting force on the pelvis[8], which may increase pelvic tilt in standing. Conversely, the hip extensor muscles, primarily hamstrings[9] are believed to increase the posterior tilting forces on the pelvis, which may increase posterior pelvic tilt in standing.

If the relaxed length of the hip muscles exerts a strong influence on pelvic tilt, then there should be a clear relationship between hip muscle length and pelvic orientation in standing. However, investigation of such a relationship will be confounded by interindividual variability in pelvic bony anatomy[10]. Specifically, differences in the morphology of individual pelves can lead to differences in the relative position of the anterior superior iliac spines (ASISs) and posterior superior iliac spines (PSISs) and therefore lead to differences in pelvic tilt which are not the result of interindividual differences in pelvic orientation[10]. Given the difficulty in quantifying interindividual variability in pelvic orientation, it is useful to study the effect of hip muscle stretching. As this is known to decrease passive muscle stiffness[11], it may result in a measurable change in pelvic orientation in relaxed standing and therefore provide insight into the muscle-related factors which influence posture.

Previous research has investigated both the acute effects and long-term effects of hamstring stretching[9,12]. Interestingly, this research has shown that, although stretching leads to increases in active range of movement[13], it does not translate into changes in pelvic orientation or spinal curvature in relaxed standing. This finding may imply that the hip flexor muscles exert a stronger influence on pelvic tilt than the hamstrings. Previous research has investigated the effect of hip flexor stretching, both in young subjects[14] and also in older individuals who were deemed to have hip flexor restriction[15]. Both studies showed a clear increase in passive hip extension, irrespective of the type of stretching employed. However, neither of these studies reported corresponding changes in pelvic orientation in relaxed standing, following the hip flexor stretching programme. Therefore, uncertainty still remains about the relationship between hip flexor length and pelvic tilt in standing.

It is possible that improvements in passive hip extension, which result from hip flexor stretching, may translate into increased hip extension and reduced anterior pelvic motion during walking. To investigate this idea, two previous studies have sought to quantify changes in hip and pelvic motions during walking following a hip flexor stretching programme[16,17]. Both studies observed an increase in peak hip extension after the stretching programme. However, interestingly, although small reductions in peak anterior tilt were observed, these effects were either not significant[17] or were similar in magnitude to the change observed in a control group who followed a shoulder stretching programme[16]. Again, neither study reported on changes in pelvic tilt during standing which resulted from the stretching programme. Therefore, they do not provide insight into the possible relationship between hip flexor length and pelvic tilt in relaxed standing. Given this lack of understanding, this current study sought to gain insight into the potential association between hip flexor length and pelvic tilt/lumbar lordosis by quantifying the effect of stretching on pelvic tilt and lumbar lordosis. We hypothesised that there would be an acute effect of hip flexor stretching, characterised by a decrease in pelvic tilt and a corresponding reduction in lumbar lordosis.

Methods

A sample of 23 healthy male volunteers were recruited to participate in the study through email and media advertisement. Ethical approval was granted by the University of Salford Ethics Approval Panel and informed consent obtained for each participant. All volunteers were initially screened for eligibility and excluded if they had experienced musculoskeletal pain within the previous 12 months, had a history musculoskeletal disease or had ever had surgery for a musculoskeletal condition. Our sample size was based on an a priori power analysis with α=0.05, power = 0.8 and an effect size of =0.58 SD. This effect size was determined from previous research on hip flexor stretching[14] which reported an SD in TT hip extension of between 3° and 5° (we assumed 4)° and a change of 14° over 6 weeks. We assumed an effect of 14°/6 = 2.3 in a single session, giving an effect size of 2.3°/4° = 0.58.

Given our hypothesis, we used a one-tailed test, which indicated a minimum of 20 participants would be required. The decision to include only male subjects was made to increase homogeneity within the group. Demographic characteristics of the sample are provided in Table 1.

TABLE 1 ABOUT HERE

For each participant, we measured pelvic tilt and lumbar lordosis in a habitual standing position, along with passive hip extension in supine lying. These measurements were performed before and immediately after a hip flexor stretching protocol. To measure pelvic tilt, we used the palpation meter (PALM), see Figure 1. For this measurement, the examiner located the ASIS and PSIS via palpation and applied a small reflective sticker bilaterally over each point. The arms of the PALM meter were then placed over the reflective stickers in order to measure the pelvic tilt angle, defined as the angle between the horizontal and the line joining the ASIS and PSIS[10]. This measurement was taken on both the left and the right side of each participant. This measurement has been shown to be reliable with interclass correlation coefficients for intra-rater reliability of 0.98 and inter-rater reliability of 0.89[18]. To minimise potential bias, the assessor was blinded to the PALM meter reading which was recorded by a second assessor.

FIGURE 1 ABOUT HERE

We use the modified Thomas Test (TT) to measure passive hip extension and therefore characterise hip flexor length. It has been shown that the TT is not valid unless pelvic tilt is controlled[19]. Therefore, the examiner placed a pressure biofeedback device (Chattanooga, Australia) under the subject's lumbar spine. The participant was then instructed to lie supine holding both knees to their chest and with lower gluteal folds maintained over the edge of the testing plinth. In this position, the pressure biofeedback was increased to 100mm Hg, after which the participant was asked to release the tested leg so that it was relaxed and hanging freely over the edge of the plinth. As the leg was released the experimenter monitored the pressure biofeedback device to ensure that the pressure did not reduce below 60 mmHg and therefore that there was no compensatory anterior tilting of the pelvis which could confound the measurement[19].

In the testing position, the angle of the thigh with recorded relative to the horizontal. This measurement was performed using an inclinometer placed on a ruler which was aligned with the epicondyle of knee and the greater trochanter. Again, to minimise bias, the assessor was blinded to the reading on the inclinometer which was read by a second assessor. This process was repeated separately on the left and right sides. This TT protocol has been shown to be highly repeatable between separate testing sessions, with interclass correlation coefficients for test-retest reliability of 0.99[20].

Lumbar lordosis in relaxed standing was measured using the Formetric 4D Diers system (Diers International GmbH, Germany). The Diers system uses a technique in which a pattern of structured light is projected onto the back of the participant. Distortions of this pattern are then used to calculate precise 3D surface shape. After identifying specific anatomical landmarks, the system constructs a full 3D representation of the spine which is used to derive parameters which describe spinal curvature[21]. Using this system, it is possible to quantify the angle of lumbar lordosis, defined as the angle between the surface tangents to the spine at points ITL and DM, where ITL is the inflection point between thoracic kyphosis and lumbar lordosis and DM is the point situated on the back surface between the left and right lumbar dimples. This measurement has been shown to be reliable with with interclass correlation coefficients for test-retest reliability of 0.93-0.95[22].

After initial measures of pelvic tilt, lumbar lordosis and TT hip extension had been made, a hip flexor stretching protocol was introduced. This protocol was developed using insight from the study by Ayala and Sainz de Baranda Andújar[13]. In this previous study, the author found that 12 repetitions of a 15 second stretch lead to significant improvements in flexibility when repeated 3x per week for 12 weeks. Although this current study was focused on the acute effects of stretching, we adopted a similar protocol, implementing 12 x 15 second passive stretches of the hip flexors. For each repetition, the participant was instructed to lie in supine position on the edge of the plinth with the knee of the contralateral leg held against the chest and the ipsilateral leg in a relaxed position, similar to the modified TT procedure. In this position, the experimenter applied pressure on the distal thigh of the testing leg for a duration of 15 seconds at a level which was tolerable by the participant. Following each 15 second stretch, the participant relaxed for 5 seconds. Although some previous studies have employed active hip flexor stretching[16], Winters *et al*.[15] compared passive versus active stretching of hip flexor muscles and found no differences in improvements in flexibility.

Following the stretching protocol, the participant was instructed to walk up and down the room for 30 seconds, after which the measurements of pelvic tilt, lumbar lordosis and passive hip extension were repeated. All data were analysed using Matlab (Mathworks, USA). In order to understand pre-stretching correlations between TT hip extension and pelvic tilt/lumbar lordosis, we calculated Spearman's rank correlation coefficients, both for the separate sides and the average of the two sides. Paired t-tests were then used to investigate potential changes in TT hip extension, pelvic tilt and lumbar lordosis which resulted from the stretching protocol. Finally, we used Spearman's rank correlation coefficients to quantify the link between the change in pelvic tilt/lumbar lordosis and the change in TT hip extension which resulted from the stretching protocol. Parametric statistical testing was used for the group comparisons as all data was found to be normally distributed. However, Spearman's rank was deemed to be the most appropriate test for the correlation analysis as it was not clear that relationships would be linear between the different pairs of variables.

Results

There were no significant correlations between pre-stretching pelvic tilt and TT hip extension when sides were considered separately (r_s=-0.34, -0.27) or when the average of the two sides was analysed (r_s =-0.33). Although there was a low pre-stretching correlation between lumbar lordosis and mean (across both sides) TT hip extension (r_s =-0.39), this failed to reach significance, p=0.07. However, following the stretching protocol, there was a significant increase in TT hip extension of 2.6° ($p<0.001$, Table 1). There was also a significant reduction of 1.2° in pelvic tilt following hip flexor stretching ($p<0.001$, Table 1). Interestingly, the stretching protocol did not result in a change in lumbar lordosis (p=0.95, Table 1). Furthermore, there were no meaningful correlations between the change in TT hip extension when sides were considered separately (r_s =-0.12, -0.22) or when the average (across sides) was analysed (r_s=-0.17). Similarly, there was no correlation between the change in TT hip extension (averaged across sides) and the change in the lumbar lordosis angle (r_s=-0.18).

Discussion

This study sought to understand the potential association between pelvic tilt and the length of the hip flexor muscles, characterized by a passive hip extension test. Importantly, following a single session of stretching, there was 2.6° increase in TT hip extension. This is consistent with the observation that acute stretching brings about a reduction in musculotendinous stiffness[11,23]. In line with our original hypothesis, this change in passive hip extension was associated with a corresponding decrease of 1.2° in pelvic tilt. This observation suggests that hip flexor length may play a role in determining sagittal plane orientation of the pelvic in relaxed standing. However, there was no clear correlation between our measure of hip flexor length (TT hip extension) and pelvic tilt before the stretching protocol, nor was there any correlation between the change in hip flexor length and the change in pelvic tilt. Although such correlations may be confounded by interindividual differences in bony shape of the pelvis[10], these findings may suggest that multiple factors influence pelvic orientation in relaxed standing. These factors are likely to include the mechanical properties of other muscles and connective tissues surrounding the pelvis along with active muscle contraction during standing[24]. It is also possible that pelvic orientation is determined by the inclination of the upper body in relaxed standing which may not change in a single session without proprioceptive/postural re-education.

Interestingly, there were no changes in lumbar lordosis following a single session of stretching, nor were there any correlations between hip flexor length and the degree of lordosis. This finding did not support our original hypothesis. Although this observation seems contrary to idea of a reciprocal relationship between pelvic tilt and lumbar lordosis[3], it is possible that the small change, of just over 1° in pelvic tilt, following hip flexor stretching, was insufficient to produce a measurable change in lumbar spine curvature. However, it is also possible that, similar to pelvis orientation, proprioceptive factors play an important role in determining spinal curvature in standing. If this is the case, then hip flexor stretching may need to be augmented with postural re-education if the clinical objective is to reduce lumbar lordosis.

It is interesting to compare the findings of this study with other research which has sought to understand the effect of hip flexor stretching. Kerrigan *et al.*[17] quantified the effect of a 10-week active stretching programme in a group of older people. Using a standing test, they observed a modest increase of 1.6° in passive hip extension, similar to the change observed in this current study. Two other studies have specifically recruited individuals with limited hip flexibility, investigating the effect of a six-week stretching programme[14,15]. Both studies reported improvements in TT hip extension of between 13-15°, considerably larger than the change observed in the current study. Although our change of 2.6° is unlikely to be clinically significant, longer-term stretching programmes in people who have restricted hip flexibility, do appear to result in large and likely important changes in hip flexibility. Our data suggest that such changes may lead to changes in pelvic orientation in relaxed standing. Therefore, future work is needed to explore the effects of longer-term stretching programmes in clinical groups, such as those with low back pain[15].

In radiographic study, Labelle *et al.* compared pelvic tilt between healthy people and individuals with different grades of spondylolisthesis[4]. The authors observed that patients, identified as grade 2, had a mean pelvic tilt angle which was 4° larger than the control group, a difference which is likely to have clinical significance. Although the change of 1.2° in pelvic tilt, observed in the current study is unlikely to be clinically significant, it is possible that larger changes in pelvic tilt may result from longer-term stretching programmes[14,15]. Specifically, a six-week programme of hip flexor stretching, in people with restricted hip mobility, appears to bring about an improvement approximately five times that observed in the current study. If such changes were to translate in to a five-fold increase in pelvic tilt, this could be associated with clinical benefits in people who have spinal pain which is deemed to result from suboptimal postural alignment. Therefore, further research is required to understand the potential of using hip flexor stretching to improve postural alignment in clinical populations.

There are some limitations to this study which should be highlighted. Firstly, we investigated the effects of a single session rather than a prolonged programme of stretching. However, the motivation for this study was to understand the potential influence of hip flexor length on pelvic tilt, rather than to understand the long-term effects of hip muscle stretching. Therefore, a within-session design was deemed appropriate. Another limitation was that we recruited a relatively homogeneous sample of male participants who appeared to have good hip flexibility compared to previous published normative data[14]. Nevertheless, even within this flexible, homogeneous group, we observed an increase in TT hip extension following the stretching protocol. Another potential limitation is that we included participants across a range of ages and BMIs (Table 1). However, although age-related differences in muscle stiffness may impact on clinical muscle tests, such as the TT, research[25] has shown only minimal differences between younger people and those up to the age of 55. Therefore, such age-related differences are unlikely to have impacted on our findings. Finally, we acknowledge that the experimenters who carried out the measurements also delivered the stretching programme. However, we attempted to minimse bias by blinding the experimenter who positioned the participant in the TT and who also made the pelvic tilt measurement to the readings on the inclinometer and PALM meter. We also used a previously validated and robust protocol for lumbo-pelvic positioning in the TT test[19,20].

Conclusions

This study showed an immediate reduction in anterior pelvic tilt following stretching of the hip flexor muscles. While this suggests that the length of hip flexor muscles may play a role in maintaining pelvic orientation in relaxed standing, there was considerable interindividual variability in the response to muscle stretching. Further research is therefore required to understand additional factors which may influence pelvic orientation in standing.

References

1. Bridger RS, Orkin D, Henneberg M. A quantitative investigation of lumbar and pelvic postures in standing and sitting: Interrelationships with body position and hip muscle length. *International Journal of Industrial Ergonomics.* 1992;9(3):235-244.

2. Le Huec J, Aunoble S, Philippe L, Nicolas P. Pelvic parameters: origin and significance. *European Spine Journal.* 2011;20(5):564.
3. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine.* 2005;30(3):346-353.
4. Labelle H, Roussouly P, Berthonnaud E. Spondylolisthesis, pelvic incidence, and spinopelvic balance: a correlation study. *Spine.* 2004;29.
5. Been E, Kalichman L. Lumbar lordosis. *The Spine Journal.* 2014;14(1):87-97.
6. Cruz-Ferreira A, Fernandes J, Kuo YL, et al. Does pilates-based exercise improve postural alignment in adult women? *Women & health.* 2013;53(6):597-611.
7. Kim H-J, Chung S, Kim S, et al. Influences of trunk muscles on lumbar lordosis and sacral angle. *European Spine Journal.* 2006;15(4):409-414.
8. Kendall F, McCreary E, Provance P, Rodgers M, Romani W. *Testing and function with Posture and Pain.* Lippincoll Williams & Wilkins; 2005.
9. Li Y, McClure PW, Pratt N. The Effect of Hamstring Muscle Stretching on Standing Posture and on Lumbar and Hip Motions During Forward Bending. *Physical therapy.* 1996;76(8):836-845.
10. Preece SJ, Willan P, Nester CJ, Graham-Smith P, Herrington L, Bowker P. Variation in pelvic morphology may prevent the identification of anterior pelvic tilt. *Journal of Manual & Manipulative Therapy.* 2008;16(2):113-117.
11. Nordez A, Cornu C, McNair P. Acute effects of static stretching on passive stiffness of the hamstring muscles calculated using different mathematical models. *Clinical biomechanics (Bristol, Avon).* 2006;21(7):755-760.
12. López-Miñarro P, Muyor J, Belmonte F, Alacid F. Acute effects of hamstring stretching on sagittal spinal curvatures and pelvic tilt. *Journal of human kinetics.* 2012;31:69-78.
13. Ayala F, Sainz de Baranda Andújar P. Effect of 3 Different Active Stretch Durations on Hip Flexion Range of Motion. *The Journal of Strength & Conditioning Research.* 2010;24(2):430-436.
14. Moreside JM, McGill SM. Hip joint range of motion improvements using three different interventions. *Journal of strength and conditioning research.* 2012;26(5):1265-1273.
15. Winters MV, Blake CG, Trost JS, et al. Passive Versus Active Stretching of Hip Flexor Muscles in Subjects With Limited Hip Extension: A Randomized Clinical Trial. *Physical therapy.* 2004;84(9):800-807.
16. Watt JR, Jackson K, Franz JR, Dicharry J, Evans J, Kerrigan DC. Effect of a supervised hip flexor stretching program on gait in elderly individuals. *PM & R : the journal of injury, function, and rehabilitation.* 2011;3(4):324-329.
17. Kerrigan D, Xenopoulos-Oddsson A, Sullivan M, Lelas J, Riley P. Effect of a hip flexor-stretching program on gait in the elderly. *Archives of physical medicine and rehabilitation.* 2003;84(1):1-6.
18. Hagins M, Brown M, Cook C, et al. Intratester and Intertester Reliability of the Palpation Meter (PALM) in Measuring Pelvic Position. *Journal of Manual & Manipulative Therapy.* 1998;6(3):130-136.
19. Vigotsky AD, Lehman GJ, Beardsley C, Contreras B, Chung B, Feser EH. The modified Thomas test is not a valid measure of hip extension unless pelvic tilt is controlled. *PeerJ.* 2016.
20. Kim GM, Ha SM. Reliability of the modified Thomas test using a lumbo-pelvic stabilization. *Journal of physical therapy science.* 2015;27(2):447-449.
21. Alzyoud K, Hogg P, Snaith B, Preece S, England A. Video rasterstereography of the spine and pelvis in eight erect positions: A reliability study. *Radiography.* 2019.
22. Guidetti L, Bonavolontà V, Tito A, Reis VM, Gallotta MC, Baldari C. Intra-and interday reliability of spine rasterstereography. *BioMed research international.* 2013;2013.

23. Ryan ED, Beck TW, Herda TJ, et al. The time course of musculotendinous stiffness responses following different durations of passive stretching. *The Journal of orthopaedic and sports physical therapy.* 2008;38(10):632-639.
24. Takaki SMP, Kaneoka KPM, Okubo YPP, et al. Analysis of muscle activity during active pelvic tilting in sagittal plane. *Phys Ther Res.* 2016;19(1):50-57.
25. Alfuraih AM, Tan AL, O'Connor P, Emery P, Wakefield RJ. The effect of ageing on shear wave elastography muscle stiffness in adults. *Aging Clinical and Experimental Research.* 2019;31(12):1755-1763.

Tables:

Table 1: Demographic characteristics of the participants

	Mean	**SD**	**Range**
Age (years)	33.61	6.71	23-50
Height (m)	1.73	0.05	1.65-1.81
Weight (kg)	80.5	12.63	65-105
BMI (kg/m^2)	26.82	4.55	21.5-37.50

Table 2: Mean (SD) pre-stretching and post-stretching results for the TT (Thomas test) hip extension, pelvic tilt and lumbar lordosis. Average (across left and right sides) have been presented for TT (Thomas test) hip extension, pelvic tilt with a negative TT hip extension angle indicating a thigh angle below the horizontal.

	TT hip extension	Pelvic tilt (mean)	Lumbar lordosis
Pre-stretching	7.5 (4.7)°	7.9 (2.7)°	35 (8)°
Post-stretching	10.1 (4.4)° *	6.7 (2.5)° *	35 (7)°

Significant changes ($p<0.01$) are indicated with an *.

Figures:

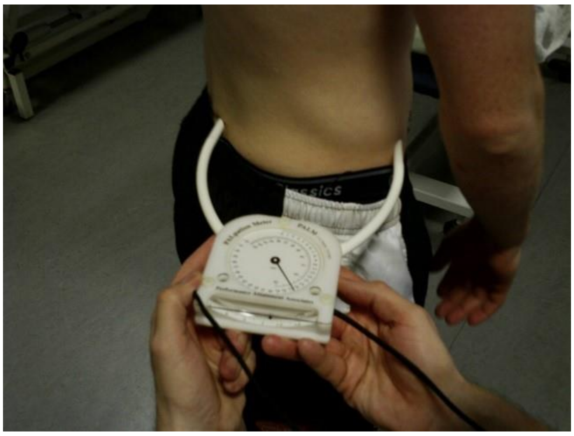

Figure 1: Use of the PALM meter to measure pelvic tilt