Accepted Manuscript

Title: Single leg stance control in individuals with symptomatic Gluteal Tendinopathy

Author: Kim Allison Kim L. Bennell Alison Grimaldi Bill Vicenzino Tim V. Wrigley Paul W. Hodges

PII:	S0966-6362(16)30099-6
DOI:	http://dx.doi.org/doi:10.1016/j.gaitpost.2016.06.020
Reference:	GAIPOS 4807
To appear in:	*Gait & Posture*
Received date:	11-1-2016
Revised date:	6-6-2016
Accepted date:	16-6-2016

Please cite this article as: Allison Kim, Bennell Kim L, Grimaldi Alison, Vicenzino Bill, Wrigley Tim V, Hodges Paul W.Single leg stance control in individuals with symptomatic Gluteal Tendinopathy.*Gait and Posture* http://dx.doi.org/10.1016/j.gaitpost.2016.06.020

TITLE PAGE

Title:

Single leg stance control in individuals with symptomatic Gluteal Tendinopathy

Authors & Affiliations:

Kim Allison[1], Kim L Bennell[1], Alison Grimaldi[2], Bill Vicenzino[3], Tim V Wrigley[1], and Paul W. Hodges[3]

[1] The University of Melbourne, Department of Physiotherapy, 161 Barry St, Parkville, VIC 3010 Australia

Email: kim.allison@unimelb.edu.au, k.bennell@unimelb.edu.au, timw@unimelb.edu.au

[2] Physiotec Physiotherapy, 23 Weller Rd, Tarragindi, QLD, 4121, Australia

Email: info@dralisongrimaldi.com

[3] The University of Queensland, School of Health & Rehabilitation Sciences, Brisbane, QLD 4072, Australia

Email: b.vicenzino@uq.edu.au, p.hodges@uq.edu.au

Corresponding Author

Kim Allison, Bachelor of Physiotherapy (BPhty)

Department of Physiotherapy, University of Melbourne

161 Barry St Parkville, VIC 3010 Australia

Ph: +61 3 83444171   Fax: +61 3 8344 4188

Email: kim.allison@unimelb.edu.au

Word count abstract: 250   **Word count main text: 3000**

Highlights

- Gluteal tendinopathy is associated with altered kinematics in single leg stance
- Hip kinematics during weight shift differ in those with gluteal tendinopathy
- Pelvic kinematics in single leg stance differ in those with gluteal tendinopathy
- Hip abductor weakness influences pelvic kinematics in gluteal tendinopathy

SINGLE LEG STANCE CONTROL IN INDIVIDUALS WITH SYMPTOMATIC GLUTEAL TENDINOPATHY

Journal: Gait and Posture

Background

Lateral hip pain during single leg loading, and hip abductor muscle weakness, are associated with gluteal tendinopathy, but it has not been shown how or whether kinematics in single leg stance differ in those with gluteal tendinopathy.

Purpose

To compare kinematics in preparation for, and during, single leg stance between individuals with and without gluteal tendinopathy, and the effect of hip abductor muscle strength on kinematics.

Methods.

Twenty individuals with gluteal tendinopathy and 20 age-matched pain-free controls underwent three-dimensional kinematic analysis of single leg stance and maximum isometric hip abductor strength testing. Maximum values of hip adduction, pelvic obliquity (contralateral pelvis rise/drop), lateral pelvic translation (ipsilateral/contralateral shift) and ipsilateral trunk lean during preparation for leg lift and average values in steady single leg stance, were compared between groups using an analysis of covariance, with and without anthropometric characteristics and strength as covariates.

Results.

Individuals with gluteal tendinopathy demonstrated greater hip adduction (standardized mean difference (SMD)=0.70, *P*=0.04) and ipsilateral pelvic shift (SMD=1.1, *P*=0.002) in preparation for leg lift, and greater hip adduction (SMD=1.2, *P*=0.002) and less contralateral pelvic rise (SMD=0.86, *P*=0.02) in steady single leg stance than controls. When including strength as a covariate, only between-group differences in lateral pelvic shift persisted (SMD=1.7, *P*=0.01).

Conclusion.

Individuals with gluteal tendinopathy use different frontal plane kinematics of the hip and pelvis during single leg stance than pain-free controls. This finding is not influenced by pelvic dimension or the potentially modifiable factor of body mass index, but is by hip abductor muscle weakness.

1. Introduction

Lateral hip pain associated with gluteal tendinopathy (GT) is most frequent in women aged over 40 years [1, 2], with symptoms aggravated in single leg loading during gait [2, 3]. GT involves tendinopathic change of the gluteus minimus and medius muscles [4, 5], two primary hip abductor muscles responsible for maintaining alignment of the pelvis relative to the femur in the frontal plane (controlling hip adduction) during single leg loading [6]. Hip abductor pathology and weakness associated with GT [1, 7] would be expected to contribute to compromised pelvic control (contralateral pelvic drop/ hip adduction). Such changes could lead to tensile and compressive overload of the gluteal tendons against the greater trochanter [8] with a potential role in the development and/or perpetuation of the condition.

Clinicians commonly visually assess pelvic alignment in the frontal plane during transition to [9], and during [9, 10], single leg stance (SLS) in evaluation of lower limb kinematics. Pelvic obliquity is usually referenced to the horizontal as an indication of hip adduction angle (pelvis relative to femur) [11, 12]. However hip adduction will also increase if the pelvis translates in the frontal plane over the grounded foot (**Figure 1**). An association between altered kinematics and GT is largely based on clinical supposition [13-15] as only one study reports pelvis position during SLS in GT [4]. On the basis of visual observation, Bird et al. categorized trunk and pelvic position during SLS as ‘normal’ or ‘abnormal’, reporting abnormal pelvic position associated with GT [4]. The authors did not provide a definition of ‘abnormal’, limiting inferences that can be drawn from the data. Quantification of kinematics is necessary.

The aim of this study was to compare frontal plane trunk, pelvic and hip kinematics in preparation for, and during, SLS in individuals with GT and pain-free controls. A secondary aim was to investigate the influence of hip abductor strength on SLS kinematics by inclusion as a covariate in our analysis. We hypothesized that individuals with GT would exhibit greater contralateral pelvic drop, ipsilateral pelvic translation and hip adduction of the stance leg in transition from bipedal to SLS and during a 2-second period of SLS with the pelvis maintained in steady alignment.

2. Methods

2.1 Sample size

A sample size calculation was performed based on between-group differences of pelvic obliquity of 2.9 degrees (95%CI 1.2,5.2) during a SLS task in individuals with and without patellofemoral pain syndrome (a condition similarly associated with hip abductor weakness and altered pelvic kinematics) [16], in the absence of previous studies in GT. In order to detect a between-group difference of 2.9 degrees, with 80% power and an alpha level of 0.05, a sample of 20 subjects were required for each group.

2.2 Participants

Twenty participants aged 35 to 70 with unilateral GT and 20 age-matched (within 3years) controls were recruited from the community using local and national newspaper advertisements. Control participants were free of musculoskeletal injury, neurological or systemic diseases affecting gait or balance. Individuals with GT had a primary *clinical* and *radiological* diagnosis of symptomatic GT. Clinical diagnosis was made by a registered physiotherapist with 9 years' experience based on the following criteria: unilateral lateral hip pain [1, 17] (in the absence of groin pain) present for ≥three months at a severity of ≥4 on an 11-point numeric pain-rating-scale (NRS) (0="no pain"; 10="worst pain imaginable"), reproduction of lateral hip pain ≥4 on the NRS with palpation of the greater trochanter [1, 17] and during ≥1 of six clinical tests used for GT diagnosis [13, 17] (Supplementary Material). Magnetic Resonance Inclusion (MRI) criterion was a primary diagnosis of GT per the classification criteria of Blankenbaker et al [5]. Exclusion criteria were: radiological evidence of hip osteoarthritis (Kellgren and Lawrence Grade≥2 [18]); other musculoskeletal injury, neurological or systemic disease that could affect balance/gait. The institutional Human Research Ethics Committee approved the study. Participants provided written informed consent.

2.3 Experimental Protocol

2.3.1 Hip abductor muscle strength

Isometric hip abductor strength testing was performed in supine, using a Lafayette Manual Muscle Tester 01160/01163/01165 (Lafayette Instrument Co, USA) fixed above the lateral malleoli as per previously reported protocol [7]. Three trials of maximum isometric hip abduction were performed against the dynamometer and overall maximum force output (N) converted to torque, by multiplying by the lever arm (m; greater trochanter to dynamometer), and normalized to body mass (Nm/kg).

2.3.2 Single leg stance analysis

To enable three-dimensional movement analysis, retro-reflective markers were placed on the participant in accordance with Besier et al [19]. Marker trajectory was recorded by a twelve-camera (MXF20/F40) Vicon motion capture system (Oxford, UK). Knee joint centers were determined from mean helical axes calculated from five consecutive squats [19] and hip joint centers from the regression equations of Harrington et al [20]. To define contralateral toe-off (commencement SLS), ground reaction force data (GRF) were collected at 1200 Hz from two AMTI-OR6-6-2000 force platforms (Advanced Medical Technology, MA, USA).

Participants were asked to find their natural standing position with one foot on each force plate (5cm apart in the laboratory floor). Instruction was given to lift the 'left' or 'right' leg to ~45 degrees hip flexion, and maintain the position for ~8-seconds (**Figure 2**). Two practice trials were given, after which three left and three right trials were performed (random order). Participants rated any pain experienced using the NRS.

2.4 Data management

Marker trajectory and force plate data were low-pass filtered at 6Hz with a dual-pass 2nd order Butterworth filter. Frontal plane trunk, pelvic and hip angles were calculated from SLS trials using the UWA direct kinematics model programmed in Vicon BodyBuilder software [19]. Pelvic angles were extracted using a rotation-obliquity-tilt Cardan angle sequence [21]. Lateral translation of the pelvis was represented by the horizontal distance of the calcaneal marker from a vertical line descending from the midpoint between the ASIS markers (**Figure 1**), normalized to half the distance between the ASISs and expressed as a percentage; to account for the likely wider base of support with greater pelvic width, and to provide a relative measure of the medio-lateral position of the pelvis over the fixed foot that could be interpreted clinically (**Figure 2**).

2.4 Data analysis

For GT participants, the weight-bearing 'test' limb was the painful side, and for controls the 'test' side randomly assigned via coin toss. SLS trials were explored to ensure the participant reached a SLS position in which the pelvis maintained in a steady position without excessive trunk sway for ≥4-seconds. GRF data from the force plate under the test leg during the 4-second period were evaluated to confirm a 120-ms window at which the variation of the medio-lateral component of the GRF was at a minimum. Participants' self-selected stance position was defined at the first frame of the recording. Toe-off was defined as the instant the vertical GRF from the force plate underneath the lifting leg fell below 20Newtons.

For each trial, values of hip adduction, pelvic obliquity, trunk lean and lateral pelvic translation were extracted for each participant's self-selected stance position (start of each trial), and *maximum* values during the period prior to toe off. Values were averaged over the three repetitions. Mean values of ipsilateral trunk lean, hip adduction, pelvic obliquity and lateral translation during the 120-ms period of maintained SLS were calculated for each trial and averaged.

2.5 Statistical analysis

Data analysis was conducted using IBM SPSS Statistics software version 22 (IBM, NewYork, USA) and alpha level α=0.05 used for all statistical tests. Independent t-tests were used to compare hip abductor muscle strength and descriptive data between groups when normally distributed, and Mann Whitney-U tests when non-normally distributed. An analysis of variance, followed by an analysis of covariance (ANCOVA), was used to compare kinematic values between groups, with BMI, greater trochanteric width and inter-ASIS width as covariates (based on between-group differences [see *Table 1*]), followed by hip abductor strength. As some participants experienced pain during the task (see *Results*), between-group comparisons were repeated including pain during testing as a covariate and a linear correlation performed between pain and kinematic variables.

3. Results

The groups were comparable for age, sex, height and dominance of the test limb (9 dominant) (**Table 1**). The GT group had significantly greater BMI, inter-ASIS and greater trochanteric widths (all $P<0.05$) and significantly less maximum isometric hip abductor strength (mean-difference -0.51Nm/kg; 95%CI -0.66,-0.36, $P=0.001$) (**Table 2**).

The median (IQR) value of pain experienced during SLS in the GT group was 2(3) on the NRS. Two control and two GT participants did not meet the criteria for maintained SLS and their data was not included for analysis.

Kinematics differed between groups in the bipedal self-selected neutral stance position, preparation for leg lift and during SLS (**Table 2**). Individuals with GT stood with the foot of the test leg 14% closer to the midline than controls (mean-difference -14.0% of half-Inter-ASIS width; 95%CI -26,-2, $P=0.02$, Standardized Mean Difference (SMD)=0.77). In preparation for contralateral toe-off, individuals with GT moved into greater hip adduction (mean-difference 2.0 degrees; 95%CI 0.1,3.8, $P=0.04$, SMD=0.70) and lateral pelvic translation, represented by foot placement 12% closer to pelvic midline (mean-difference -12 % half-Inter-ASIS-width; 95%CI -20,-5 $P=0.002$, SMD=1.1). In the maintained SLS position, individuals with GT exhibited greater adduction (mean-difference 4.7 degrees; 95%CI 1.9,7.5, $P=0.002$, SMD=1.2) and contralateral pelvic rise was less (mean-difference 2.9 degrees; 95%CI 0.5,5.2, $P=0.02$, SMD=0.86) than controls. When adjusting for BMI, inter-ASIS and trochanteric widths the between-group differences in SLS kinematics persisted, with the exception of hip adduction in preparation for toe-off (adjusted-mean-difference 0.9 degrees; 95%CI-1.4,3.2; $P=0.45$) and foot position in bipedal stance (mean-difference -11% inter-ASIS-width; 95%CI -27,4 $P=0.15$). When additionally or alternatively (reducing the risk of Type II error) (**Table 2**) adjusting for hip abductor strength, there were no significant between-group differences in kinematics in maintained SLS, however between-group differences in lateral pelvic shift in preparation for toe-off remained significant (mean-difference -10% half-ASIS-width; 95%CI-19,3 $P=0.01$). Conversely, adjusting for pain during the task did not alter the significance of between-group comparisons. No relationship was identified between pain and any kinematic variable (all $P>0.05$).

Given significant between-group findings of greater lateral pelvic translation in individuals with GT, post-hoc bivariate correlation was performed to evaluate the relationship between foot position under the pelvis and hip adduction angles in the self-selected stance position ($R=-0.454$, $P=0.003$) and during the preparation to lift ($R=-0.364$, $P=0.02$), both significant ($P<0.05$).

3. Discussion

These results show that in contrast to pain-free controls, individuals with GT exhibit greater lateral translation of the pelvis and hip adduction in preparation for SLS, and more hip adduction and less pelvic elevation during SLS. Most between-group differences disappeared when hip abductor strength was controlled for, indicating that these movement differences were in part related to hip abductor muscle weakness.

Transition to, and maintenance of, SLS is a demanding functional task for the hip abductor muscles [6, 11], including the gluteus minimus and medius involved in GT. To maintain alignment of the pelvis in the frontal plane in SLS, these muscles, together with their passive elements and muscles that tension the iliotibial band (ITB) (tensor fascia lata, upper gluteus maximus and vastus lateralis [22]), must generate sufficient net torque to match the magnitude of the external hip adduction moment; influenced primarily by the position (and magnitude) of the centre of mass from the hip joint centre [23]. Consistent with evidence of hip abductor weakness in GT [1, 7], individuals with GT in the present study were 42% weaker than pain-free controls. Given that the major contributor to the center of mass is the trunk [24] (positioned on the pelvis), several strategies of trunk and pelvic motion have potential to influence the demand on the hip abductor muscles in SLS [25]. Healthy males receiving a superior gluteal nerve block, inducing an average 52% reduction in maximum hip abductor muscle strength, have been shown to demonstrate variable movement strategies in SLS (contralateral pelvic drop/rise +/- ipsilateral trunk lean) [25]. In contrast, individuals in the present study with hip abductor muscle weakness *and* symptomatic GT demonstrated reduced contralateral pelvic rise compared to controls, which was not evident when controlling for hip abductor weakness. Together, this data suggests that hip abductor muscle weakness together with gluteal tendon pathology contributes to contralateral pelvic drop in those with GT.

In order to move from a position of bipedal to SLS, the center of mass must be displaced laterally, via trunk/ pelvic shift, over a new (smaller) base of support [23]. Individuals with GT demonstrated greater ipsilateral pelvic shift in preparation for leg lift than controls. This could feasibly be a manifestation of those in the GT group having a greater BMI (associated with GT [26]) and pelvic width, and thus a greater external hip adduction moment (contributed to by the *magnitude* and frontal plane *position* of the centre of mass) and consequent requirement for internal abductor moment generation. This proposition was not upheld, as greater lateral shift was still seen in the GT group after normalizing lateral pelvic shift to pelvic width and including BMI/ pelvic width as covariates in our analysis. Alternatively, this movement could feasibly reflect a preparatory strategy to reduce the force-generating demand on the injured (and weaker) gluteus minimus and medius muscles and their tendons. This is likely not the case because lateral pelvic shift appeared to be independent of hip abductor muscle strength. Thus this pattern may be more indicative of altered motor control, shown to be a feature of other tendinopathies [27].

Studies of the torque-angle relationship of the hip abductor muscles in humans demonstrate that maximum abductor torque increases with hip adduction [28, 29]. It is plausible that utilizing greater hip adduction (contributed to by lateral pelvic shift) prior to leg lift may provide the hip abductor muscles with an advantage for torque generation in the presence of hip abductor muscle weakness. Alternatively, it is possible that individuals with GT may have an altered length-tension curve of the hip abductor muscles, whereby the optimal position for force generation is in a greater degree of hip adduction (and subsequently muscle elongation) than controls. It has been proposed that as a cumulative result of adopting sustained postural positions of hip adduction (elongation stress on the hip abductors) such as sitting cross-legged, individuals with GT have developed altered length-tension relationships of these muscles [10, 14]. Chronic elongation stress has been shown to result in a shift in the length-tension curve where optimal force generation requires a more lengthened position [30]. This mechanism might be relevant to the greater hip adduction angles identified in individuals with GT in SLS.

In SLS, reduced elevation of the contralateral pelvis, often described as a “Trendelenburg”, is thought to reflect dysfunction of the hip abductor muscles [11]; however the position of the non-weight bearing limb will influence the position of the pelvis and demand on the hip abductor muscles [11]. It has been demonstrated in individuals with and without hip pathology, that greater contralateral pelvic drop in SLS occurs when the non-weight bearing limb is in 30 degrees hip flexion than in 90 degrees [11]. In the present study, participants maintained SLS with the contralateral hip in 45 degrees flexion. As a result both groups achieved a position of contralateral pelvic ‘hitching’ or elevation over the stance leg. Although less contralateral pelvic rise was recorded in those with GT in SLS, it is plausible that “deficits” in control of pelvic obliquity were under-represented because of the position of the non-weight bearing limb and would be greater if the hip were flexed below 30 degrees.

The findings of the present study have several key clinical implications. Although we measured significant between-group differences in kinematics used to achieve and maintain SLS in the laboratory, it remains to be tested whether clinicians can detect such differences with visual observation. Clinicians often use the position of the pelvis relative to the horizontal as a measure of pelvic obliquity and an indicator of hip abductor function [12]; yet mean between-group differences in pelvic obliquity in SLS (2.9 degrees) were less than that of hip adduction (4.7 degrees) and less likely to be visually detectable. The difference in lateral shift of the pelvis during preparation to lift, utilizing the relative foot position to the mid pelvis, recorded in the present study might be more likely to be visually detectable. Post-hoc analysis identified a significant relationship between foot position under the pelvis in the frontal plane and hip adduction angles. Clinical use of this method might be a useful indicator of hip adduction in addition to pelvic obliquity.

This study has several strengths. First, it is the first to evaluate three-dimensional kinematics of a SLS task in those with GT. Second, the use of an age-matched control group is important given that the task could be affected by age-related changes to balance. Third, strict exclusion criteria were applied to both groups to exclude the presence of any pathology that could affect participants' balance or the ability to perform the task. Fourth, the collection and inclusion of hip abductor strength data in our analysis enabled exploration of the influence of hip abductor weakness on SLS kinematics in this group. The main limitation is inherent in the cross-sectional study design in that we cannot conclude whether the kinematic patterns identified in those with GT preceded or followed onset of GT pathology. Additionally, we did not obtain MRIs on the asymptomatic hip in those with GT or the hips of the controls. As such we cannot exclude the presence of asymptomatic GT.

4. Conclusion

In conclusion, this study showed that individuals with GT demonstrate greater hip adduction and greater lateral translation of the pelvis in preparation for single leg loading, and maintain a position of SLS in greater hip adduction and less contralateral pelvic rise than pain-free controls. Hip abductor muscle weakness appears to be an important feature of these kinematic differences. As with other tendinopathies [27], both strength and kinematics may need to be considered in the development of effective rehabilitation strategies. Further research is essential to establish the kinematic patterns used by individuals with GT during functional tasks such as gait and whether hip abductor strengthening can alter kinematic patterns during SLS and have a positive impact on recovery.

Acknowledgements

The study was supported by a National Health Research and Medical Research Council Program Grant held by Professor Kim Bennell, Professor Paul Hodges and Professor Bill Vicenzino (ID631717): an Australian Physiotherapy Association Physiotherapy Research Seeding Grant held by Kim Allison (S14-012). No other financial support or benefits from commercial sources was associated with any part of this study or manuscript.

References

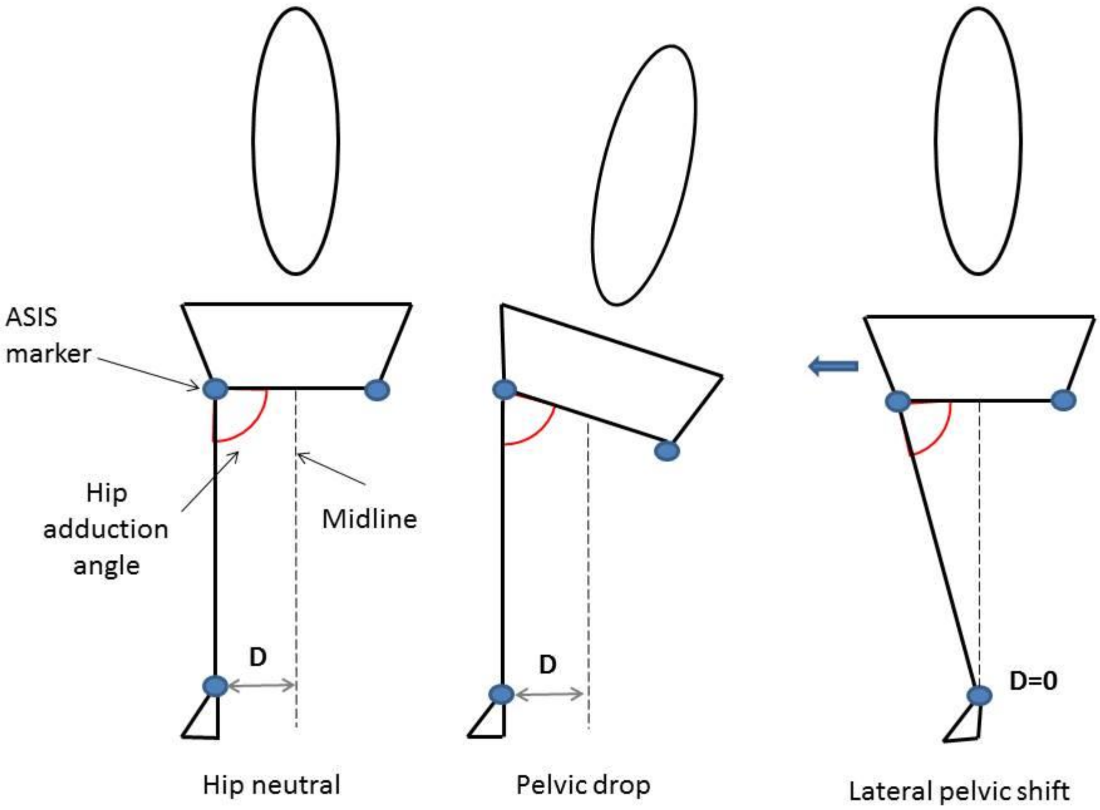
[1] Woodley S, Nicholson H, Livingstone V, Doyle T, Meikle G, Macintosh J, et al. Lateral Hip Pain: Findings From Magnetic Resonance Imaging and Clinical Examination. Journal of Orthopaedic & Sports Physical Therapy. 2008;38:313-28.
[2] Segal NA, Felson DT, Torner JC, Zhu Y, Curtis JR, Niu J, et al. Greater trochanteric pain syndrome: epidemiology and associated factors. Archives of Physical Medicine & Rehabilitation. 2007;88:988-92.
[3] Fearon AM, Cook JL, Scarvell JM, Neeman T, Cormick W, Smith PN. Greater Trochanteric Pain Syndrome Negatively Affects Work, Physical Activity and Quality of Life: A Case Control Study. The Journal of Arthroplasty. 2014;29:383-6.
[4] Bird PA, Oakley SP, Shnier R, Kirkham BW. Prospective evaluation of magnetic resonance imaging and physical examination findings in patients with greater trochanteric pain syndrome. Arthritis & Rheumatism. 2001;44:2138-45.
[5] Blankenbaker D, Ullrick S, Davis K, De Smet A, Haaland B, Fine J. Correlation of MRI findings with clinical findings of trochanteric pain syndrome. Skeletal Radiology. 2008;37:903-9.
[6] Al-Hayani A. The functional anatomy of hip abductors. Folia Morphologica. 2009;68:98-103.
[7] Allison K, Vicenzino B, Wrigley TV, Grimaldi A, Hodges PW, Bennell KL. Hip abductor muscle weakness in individuals with gluteal tendinopathy. Med Sci Sports Exerc. 2016;48:346-52.
[8] Birnbaum K, Siebert CH, Pandorf T, Schopphoff E, Prescher A, Niethard FU. Anatomical and biomechanical investigations of the iliotibial tract. Surgical and Radiologic Anatomy. 2004;26:433-46.
[9] Lee D. The Pelvic Girdle: An Integration of Clinical Expertise and Research. 4th edition ed. Philadelphia, PA: Churchill Livingstone Elsevier; 2011.
[10] Grimaldi A. Assessing lateral stability of the hip and pelvis. Manual Therapy. 2011;16:26-32.
[11] Hardcastle P, Nade S. The significance of the trendelemberg test. The Journal Of Bone And Joint Surgery British Volume. 1985;67B:741-6.
[12] Youdas JW, Mraz ST, Norstad BJ, Schinke JJ, Hollman JH. Determining Meaningful Changes in Pelvic-On-Femoral Position During the Trendelenburg Test. Journal of Sport Rehabilitation. 2007;16:326-35.
[13] Grimaldi A, Mellor R, Hodges PW, Bennell K, Wajswelner H, Vicenzino B. Gluteal Tendinopathy: A Review of Mechanisms, Assessment and Management. Sports Med. 2015;48:1107-19.
[14] Bewyer DC, Bewyer KJ. Rationale for treatment of hip abductor pain syndrome. The Iowa Orthopaedic Journal. 2003;23:57-60.
[15] Lin C, Fredericson M. Greater Trochanteric Pain Syndrome: An Update on Diagnosis and Management. Curr Phys Med Rehabil Rep. 2015;3:60-6.
[16] Nakagawa TH, Moriya ETU, Maciel CD, Serrao FV. Trunk, Pelvis, Hip, and Knee Kinematics, Hip Strength, and Gluteal Muscle Activation During a Single-Leg Squat in Males and Females With and Without Patellofemoral Pain Syndrome. Journal of Orthopaedic & Sports Physical Therapy. 2012;42:491-501.

[17] Fearon AM, Scarvell JM, Neeman T, Cook JL, Cormick W, Smith PN. Greater trochanteric pain syndrome: defining the clinical syndrome. British Journal of Sports Medicine. 2013;47:649-53.
[18] Kellgren J, Lawrence J. Radiological Assessment of Osteo-Arthrosis. Annals of the Rheumatic Diseases. 1957;16:494-502.
[19] Besier TF, Sturnieks DL, Alderson JA, Lloyd DG. Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. J Biomech. 2003;36:1159-68.
[20] Harrington ME, Zavatsky AB, Lawson SEM, Yuan Z, Theologis TN. Prediction of the hip joint centre in adults, children, and patients with cerebral palsy based on magnetic resonance imaging. J Biomech. 2007;40:595-602.
[21] Baker R. Pelvic angles: a mathematically rigorous definition which is consistent with a conventional clinical understanding of the terms. Gait & Posture. 2001;13:1-6.
[22] Stecco A, Gillar W, Hill R, Fullerton B, Stecco C. The anatomical and functional relation between gluteus maximus and fascia lata. Journal of Bodywork and Movement Therapies. 2013;17:512-7.
[23] McLeish RD, Charnley J. Abduction forces in the one-legged stance. J Biomech. 1970;3:191-209.
[24] Winter DA. Human balance and posture control during standing and walking. Gait & Posture. 1995;3:193-214.
[25] Kendall KD, Patel C, Wiley P, Pohl MB, Emery CA, Ferber R. Steps Toward the Validation of the Trendelenburg Test: The Effect of Experimentally Reduced Hip Abductor Muscle Function on Frontal Plane Mechanics. Clinical Journal of Sport Medicine. 2013;23:45-51.
[26] Fearon AM, Stephens S, Cook JL, Smith PN, Neeman T, Cormick W, et al. The relationship of femoral neck shaft angle and adiposity to greater trochanteric pain syndrome in women. A case control morphology and anthropometric study. British Journal of Sports Medicine. 2012;46:888-92.
[27] Rio E, Kidgell D, Moseley GL, Gaida JE, Docking S, Purdam C, et al. Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a narrative review. British Journal of Sports Medicine. 2015 50:209-15.
[28] Neumann DA, Soderberg GL, Cook TM. Comparison of maximal isometric hip abductor muscle torques between sides. Physical Therapy. 1988;68:496-502.
[29] Kulig K, Andrews J, Hay J. Human Strength Curves. Exercise and Sport Sciences Reviews. 1984;12:417-66.
[30] Gossman MR, Sahrmann SA, Rose SJ. Review of Length-Associated Changes in Muscle: Experimental Evidence and Clinical Implications. Physical Therapy. 1982;62:1799-808.

Figure Captions

Figure 1. Contribution of position of pelvis on femur to hip adduction angle. Pelvic drop is measured relative to the horizontal. Lateral pelvic shift over the fixed foot is measured as the distance from the calcaneal marker and the inter-ASIS marker defined midline and normalized to pelvic width to account for varying base of supports likely associated with greater pelvic width. Hip adduction is increased by either drop of the contralateral side of the pelvis (pelvic obliquity) or by translation of the pelvis towards the ipsilateral side.

Figure 2. Participant performing the SLS task. Lateral translation of the pelvis is highlighted as the distance of the calcaneal marker from the projection of the midpoint between the ASIS to the floor, and values normalized to half the distance between the right and left ASIS.


ASIS
marker
Hip
adduction
angle
Midline
D
Hip neutral
D
Pelvic drop
D=0
Lateral pelvic shift

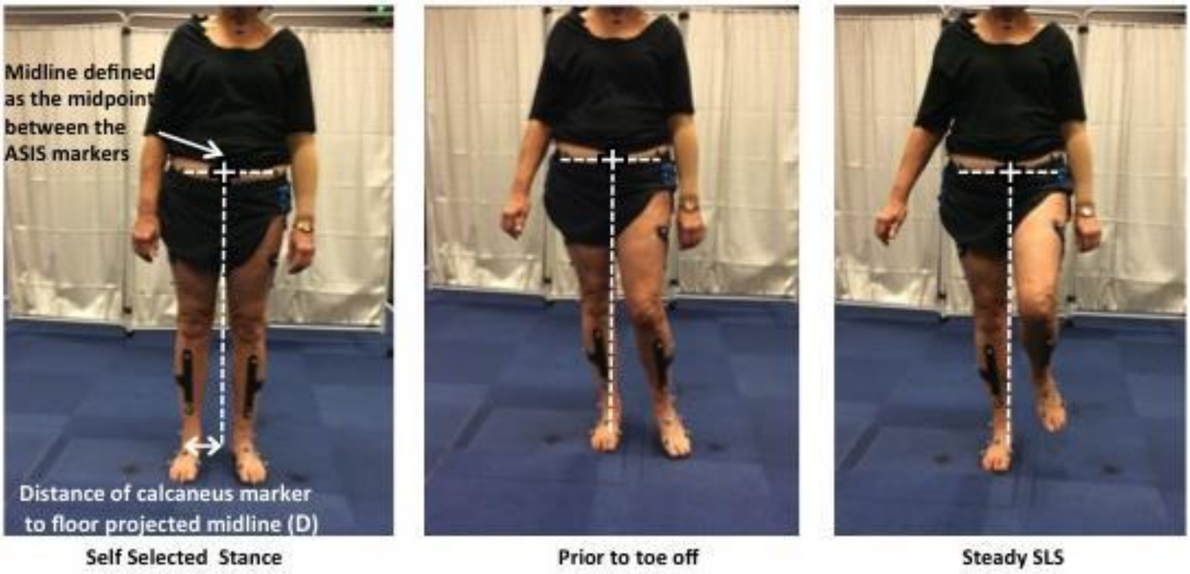

Midline defined as the midpoint between the ASIS markers
Distance of calcaneus marker to floor projected midline (D)
Self Selected Stance
Prior to toe off
Steady SLS

Table 1. Descriptive characteristics of the study sample (mean (standard deviation) unless otherwise stated)

	Gluteal Tendinopathy	Control	Mean Difference (95% CI)	p value
Age, years	54.3 (9.6)	51.8 (9.3)	3.1 (-3.4, 8.6)	0.165
Height, m	1.67 (0.09)	1.69 (0.11)	-0.11 (-0.08, 0.06)	0.744
Mass, kg	77.7 (13.4)	69.4 (14.8)	8.2 (-1.0, 17.4)	0.079
Body mass index, kg/m^2	27.6 (3.9)	24.2 (3.0)	3.4 (1.1, 5.6)	**0.004***
Inter ASIS width, mm	266 (22)	232 (23)	34 (20, 48)	**<0.001***
Greater Trochanteric width, mm	375 (27)	347 (33)	27 (8, 47)	**0.006**
Sex, n (%)				
Female	14 (70%)	14 (70%)	-	-
Male	4 (30%)	4 (30%)	-	-
Test Hip[$]	Right = 8 Left = 10	Right = 9, Left =9	-	-
Dominance of Test Limb[#]	Dominant = 9 Non Dominant = 9	Dominant = 9, Non Dominant = 9	-	-

$ - 'Symptomatic Hip' designated in control participants by a coin toss

- Defined as the leg used to kick a ball

** - P<0.05 for between group comparison with t-test for independent samples*

Table 2. Maximum isometric hip abductor muscle strength and frontal plane kinematics of the trunk, hip and pelvis in individuals with gluteal tendinopathy and pain-free controls in neutral stance, in preparation for contralateral leg lift and in a position of maintained SLS

	Gluteal Tendinopathy	Control	Mean Difference (95% CI)	*P* value	*Adjusted P value*[+]
Hip abductor strength, Nm/kg	0.65 (0.21)	1.16 (0.23)	-0.51 (-0.66, -0.36)	<0.001	-
Hip adduction, degrees					
Neutral stance	2.0 (3.0)	0.4 (3.2)	1.7 (-0.3, 3.7)	0.09	0.16
Maximum to contralateral toe off	5.1 (2.8)	3.1 (3.0)	2.0 (0.1,3.8)	**0.04***	0.44
Maintained SLS	1.5 (3.9)	-3.2 (4.3)	4.7 (1.9, 7.5)	**0.002***	0.63
Pelvic obliquity in the frontal plane, degrees					
(Negative value indicates non-weight bearing side of pelvis elevated relative to stance side)					
Neutral stance	-0.3 (1.6)	-0.5 (2.1)	0.2 (-1.0, 1.4)	0.75	0.71
Maximum to contralateral toe off	0.8 (1.6)	0.6 (1.7)	0.3 (-0.8, 1.4)	0.55	0.56
Maintained SLS	-6.9 (3.4)	-9.8 (3.5)	2.9 (0.5, 5.2)	**0.02***	0.94
Lateral translation of the pelvis, minimum foot placement from midline: half-ASIS (%) [#]					
Neutral stance	66 (20)	81 (18)	-14 (-26,-2)	**0.02***	0.08
Maximum to contralateral toe off	12 (12)	24 (11)	-12 (-20, -5)	**0.002***	**0.01***
Maintained SLS	-22 (11)	-26 (11)	5 (-3, 13)	0.23	0.81
Ipsilateral trunk lean (frontal plane), degrees					
Neutral stance	-0.9 (2.3)	0.6 (2.1)	-1.5 (-2.9, 0.05)	**0.04***	0.06

Maximum to contralateral toe off	0.9 (2.7)	1.3 (2.3)	0.8 (-1.9, 1.3)	0.68	0.58
Maintained SLS	1.1 (3.4)	0.6 (2.6)	0.5 (-1.6, 2.6)	0.63	0.54

Data expressed as the unadjusted mean (standard deviation), [+] *maximum hip abductor strength as a covariate,* * - P<0.05

- 0% represents a foot placement under the midpoint of the ASIS, 100% represents placement under the ASIS, and negative values indicate foot has crossed the midline