THE RELATIONSHIP OF FEMORAL TORSION AND LOWER LIMB INJURY

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The Prophet Muhammad (peace be upon him) said:
"One who treads a path in search of knowledge has his path to Paradise made easy by God…" –
~Riyadh us-Saleheen, 245~

To my husband Yazid and my kids, Zaim, Dina, Doa and Zyad for their unwavering love, supports, encouragement and belief in me in persuing my PhD.

THE UNIVERSITY OF SYDNEY

Candidate's statement

I, **ELIZA HAFIZ**, hereby declare that the work contain within this thesis is my own and has not been submitted to any other university or institution as part or as a whole requirement for any higher degree.

I, **ELIZA HAFIZ**, hereby declare that I was the principal researcher of all work included in this thesis, including work published with multiple authors.

In addition, ethical approval from The University of Sydney Human Ethics Committee was granted for the three studies presented in this thesis. Participants were required to read the participants information statement and informed consent was gained prior to data collection.

Name Eliza Hafiz

Signature

Date 29 August 2014

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ABSTRACT

Research about femoral torsion has existed since the late 1980's with the focus on developing a method to measure femoral torsion. Identifying the degree of femoral torsion has become important because excessive antetorsion of the femur has been associated with hip pathology. In addition, it is important to identify the degree of femoral torsion prior to placement of a hip prosthesis and prior to derotational osteotomy for children with congenital excessive femoral antetorsion, which is seen in cerebral palsy, hip dysplasia and Blount's disease. The gold standard for measuring femoral torsion is a CT scan, which is invasive therefore limiting its usage especially in children.

While research on femoral torsion has been narrowed to hip pathology and correcting deformity, excessive femoral antetorsion is thought to impact structures distal to the hip therefore increasing the risk of developing lower limb injury. Since the relationship between femoral torsion and lower limb injury is unknown, a systematic review is presented in Chapter 2 that looked at the relationship between femoral torsion and other hip characteristics as a risk factor for lower limb injury. Excessive range of external rotation and increased strength may increase the risk of lower limb stress fracture and patellofemoral pain. Weaker hip external rotators and stronger hip abductors were found to significantly increase the risk of developing patellofemoral pain. Greater range of hip external rotation was also found to be a factor in increasing the risk of lower limb stress fracture however the figure is too small to be considered a clinically worthwhile effect. Although hip strength and hip

range of motion were found to be risk factors for lower limb injury, no prospective study investigating the relationship between femoral torsion and lower limb injury was found. Therefore, one of the aims of this thesis was to provide preliminary data to uncover this relationship.

Another aim of the work presented in this thesis was to develop a new ultrasound imaging protocol to assess femoral shaft torsion utilising a new landmark on the greater trochanter, 'the ridge'. The protocol showed excellent intra-rater reliability ($ICC_{2,1}$ = 0.98; 95% CI 0.97 to 0.99), and inter-rater reliability ($ICC_{2,1}$ = 0.97; 95% CI 0.95 to 0.98). Fifty per cent of the measurements were within 1^o both within and between raters and within 2.7^o for 80% of the measurements. The largest difference between raters was 9.3^o. Standard error of measurement (SEM) was 0.5 degrees and 0.6 degrees respectively for intra-rater and inter-rater reliability measurements. The excellent reliability supports its usage in the clinical setting. This work is presented in chapter 3.

Consequently, using the newly developed reliable method, the relationship between femoral torsion and hip proprioception was examined in healthy adults (n=40). Hip proprioceptive acuity was measured using an active reproduction of movement in three different angles; 10% of neutral, 50% or mid-range and 90% of maximum external rotation. Greater range of medial shaft torsion was found to be associated with better hip proprioceptive acuity only at the angle near the end of maximum external rotation (r=-0.325, p=0.04) not at 10% (r=0.019, p=0.909) and 50% (r=0.116, p=0.478). The detail of this study is described in chapter 4 of this thesis.

A cross-sectional study investigated the relationship between femoral shaft torsion and lower limb injury in dancers (n=80). No difference was found in the magnitude of femoral shaft torsion between injured and non-injured dancers ($p = 0.94$). The relationship between femoral shaft torsion and eight other hip measures was also investigated. Femoral shaft torsion was found to have a very weak, negative correlation with range of hip external rotation ($r = -0.034$, $p=0.384$) and turnout ($r = -0.066$, $p=0.558$). The association between femoral shaft torsion with all other variables was also found to be very weak. This study is described in detail in Chapter 5.

Overall the results of the studies documented in this thesis: describe the development of a novel femoral torsion measurement tool, identify femoral shaft torsion as a measurable component of femoral torsion, and provide preliminary data and inferences regarding the relationship between femoral torsion, distal lower limb injury and lower limb proprioceptive acuity in a high risk population of dancers. It is proposed that future research will determine the extent to which femoral torsion poses a lower limb injury risk, which will inform the modification of screening protocols. The findings of this thesis will also assist clinicians to direct their prophylactic management to joints and soft tissues at risk. If a time-frame for development of FT can be identified, modified training loads may be investigated to enhance optimal FT and determine whether this minimises injury risk. This new information therefore will also provide a basis for future research that would likely be in longitudinal studies establishing relationships, hence providing useful information for coaches and clinicians regarding designing alternative methods of training in preventing lower limb injuries. The body of knowledge provided by this thesis will also inform researchers in determining the measures of the hip to be used in future research which might be worthwhile investigating in relation to lower limb injury.

Parts of the work presented in this thesis have been published and/or presented in the following forums:

PEER REVIEWED PAPERS

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CONFERENCE PRESENTATIONS - ORAL

Australia Society of Performing Arts Healthcare (ASPAH) Conference 21 – 23 October 2011 "*Development of a novel method of measuring femoral torsion using real time ultrasound*"

CONFERENCE PRESENTATIONS - POSTER

The American College of Sports Medicine (ACSM) Conference 24 – 28 May 2013 "*Do hip characteristics predispose to lower limb injury*"

OTHERS

Seminar titled "*The important of femoral torsion knowledge in ballet dancers*" presented for Dancers' Health Week organised by The Canberra Dance Theatre

بسم الله الرحمن الرحيم

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CHAPTER 1

Structural anatomy of the hip

The anatomical structure of the hip can be described based on its arthrology and morphology. Understanding the arthrology and morphology of the hip will provide a basis for the discussion of femoral torsion which is the focus of this thesis.

Arthrology

The hip is an enarthrosis, i.e: a synovial joint of the ball and socket variety. Though more stable than the shoulder, as befits a weight-bearing joint, the hip is considerably less mobile. [1, 2] Stability at the hip is assured primarily by the reciprocal shape of articular contact areas and their fitting or congruence. The head of the femur, the ball of the enarthrosis, nestles deeply in the acetabulum of the ilium. The acetabular labrum, a fibrocartilaginous lip, further increases the depth of the socket. The acetabular fossa is incomplete inferiorly and the gap, the acetabular notch, is bridged by the transverse acetabular ligament. [2] Branches of the obturator and medial circumflex femoral arteries pass through the acetacular notch to the fovea on the femoral head, carried there by the ligament of the head of the femur.

Osteology/Morphology

The femur, or thigh bone, like other long bones is comprised of the diaphysis (the shaft), and two ends; the proximal and distal metaphyses and epiphyses (Figure 1A). [2, 3] The proximal end of the femur is formed by the head, neck, and the greater and lesser trochanter (Figure 1B). The distal end of the femur consists of two oblong eminences known as the condyles, the patellar surface, and the intercondylar notch.[3]

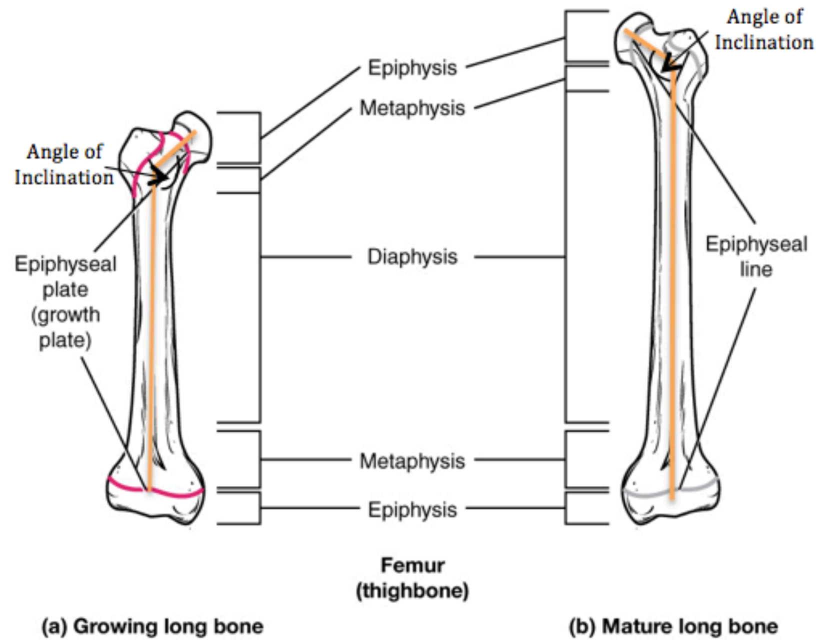

Figure 1A Osteology of the femur
(Source: http://cnx.org/content/m46301/latest/)

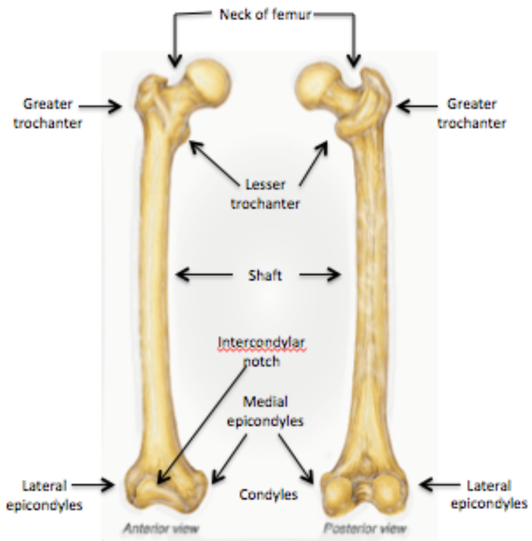

Figure 1B Bony landmarks on femur; depicting the greater and lesser trochanter, condyles, neck of femur, intercondylar notch (Candidate's own work)

The head of the femur is slightly more than a half spherical structure. The head is offset from the diaphysis of the femur by approximately 125 degrees.

This offset is achieved by the interposition of the neck of the femur which distances the limb from the trunk thus performing the same function as the clavicle at the shoulder.[1] The greater and lesser trochanter, are two prominent processes which afford attachment and leverage for the muscles that rotate the thigh on its axis.

The shaft of the femur is connected to the head by the neck of femur. The shaft, almost cylindrical in form is the attachment for some of the muscles that extend the knee; the vasti and the adductors.[3] The condyles of the distal femur are separated posteriorly and inferiorly by the intercondylar notch that serves as a site for anterior and posterior cruciate ligament attachment.[2]

The trabecular and osseous architectural complexity and size of the femoral structure makes it the longest and strongest bone in the skeletal system [2, 3] as befits its paramount role as a supporting structure during weight bearing activities. Due to its significant role in the skeletal system, deformation anywhere in the femur can affect structures lower in the kinetic chain which in a long term may cause injury and permanent disability to the lower limb. [4-6]

Of many types of deformities in the femur, malalignment is one possibly induced by both congenital and physical factors. [7, 8] Angle of inclination of the femur and the range of femoral torsion are two types of alignment variations commonly described. [9-11] The angle of inclination (normally 125°) is best viewed in the coronal plane and measured as the angle between the femoral neck and shaft. [1] This angle is slightly less in females because of their wider pelvis. The angle of torsion, known as femoral torsion, is best viewed in the transverse plane and is defined as the angle subtended by the neck axis and the horizontal line made by the posterior condyles of the femur.[1] Normal femoral torsion is between 10-20º both in male and females.[12, 13] Both the angle of inclination and the angle of femoral torsion are determined by the orientation of the epiphyseal plates in the femur.[14] In this thesis, only the angle of torsion, femoral torsion, will be described and used.

Torsion of the femur: description and definition

The lower extremity performs its major movements in a plane which is roughly parallel to the median sagittal plane of the body. Therefore the hip, the knee and the ankle joints might, consequently be expected to be oriented with their axes in the transverse plane and parallel to each other. This expectation is only realised when the lower limb is viewed from above. In this view, the neck of the femur is at an angle to the axis of the knee joint. This discordance of orientation is assumed to be caused by a twisting of the shaft of the femur, termed "torsion".[15]

Torsion is defined as the deformation of a bone by twisting a long axis, where one end is held fast and the other end is turned a on its longitudinal axis.[16] In the femur, the proximal portion is fixed while the distal end is rotated. Femoral torsion was first described in 1868 when Julius Wolff carefully studied the structural architecture of the neck of femur and described normal torsion of the femur.[16] Femoral torsion has since been quantified as the angle subtended by the axis through the femoral neck with the axis through the distal femoral condyles.[1, 12, 17, 18] This conventional definition of torsion describes the overall magnitude of rotation of the femur however, the actual site where torsion occurs remain unknown but is thought to occur at one of two sites or both: between the femoral head and neck, and/or between the greater trochanter and the condyles.

Normally, when the femoral condyles are positioned in the frontal plane, femoral torsion results in the axis of the femoral neck lying anteriorly relative to the axis of the femoral condyles (about 10-20 degrees). This is called femoral antetorsion (Figure 2). In contrast, femoral retrotorsion presents as the axis of femoral neck lying less than 10 degree anteriorly relative to the axis of the femoral condyles or lying posteriorly to the axis of the femoral condyles. There is no consensus about the normal angle of total femoral torsion. Studies in cadavers suggest 12-14^{o},[19] while in-vivo studies suggest 15-20^{o} as the normal angle of torsion. [12, 17, 18, 20]

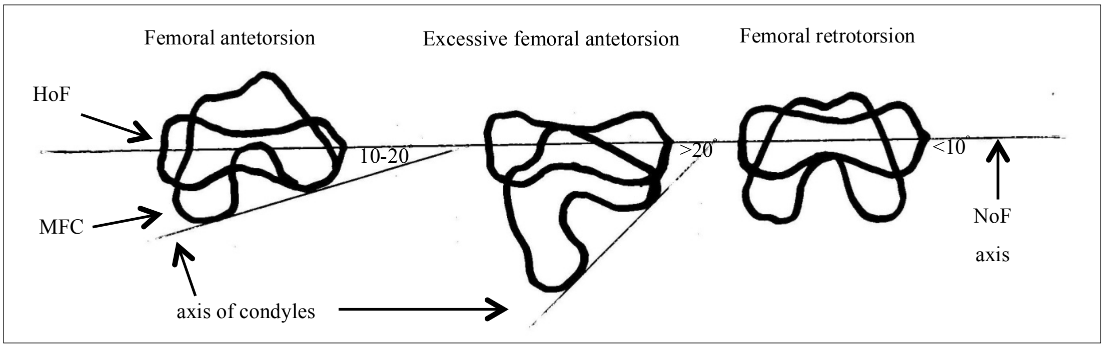

Figure 2 Torsion of the femur. A schematic drawing of femoral torsion. If the axis of the femoral neck is rotated to face more anteriorly, the femur is said to be excessively antetorted. If the axis of the femoral neck is rotated so that the head of femur lies on the sagittal plane or faces posteriorly, the femur is said to be retroverted. [16]
(HoF; head of femur, MFC; medial femoral condyle, NoF; neck of femur)
(Candidate’s own work)

There is conflicting evidence about the existence of femoral torsion in the animal kingdom. A German anatomist, Franz Altmann investigated femoral torsion in amphibians, reptiles, birds, mammals, and humans. He found femoral torsion only existed in the human population and the incidence of femoral retrotorsion was very small. [21] Conflictingly, a more recent study by Tayton [22] investigated femoral antetorsion in bipedal quadruped animals, mainly the baboon, and thirteen other quadruped animals. The angle of antetorsion in these animals ranged from 4^o to 41^o (Figure 3) with a mean antetorsion in the baboon femur of 18.8^o. Based on this evidence, it can be speculated that femoral torsion has a wide range of variation even in the animal kingdom and the same scenario may exist in humans. A simple yet reliable and valid method of measurement is needed to accurately measure the amount of femoral torsion.

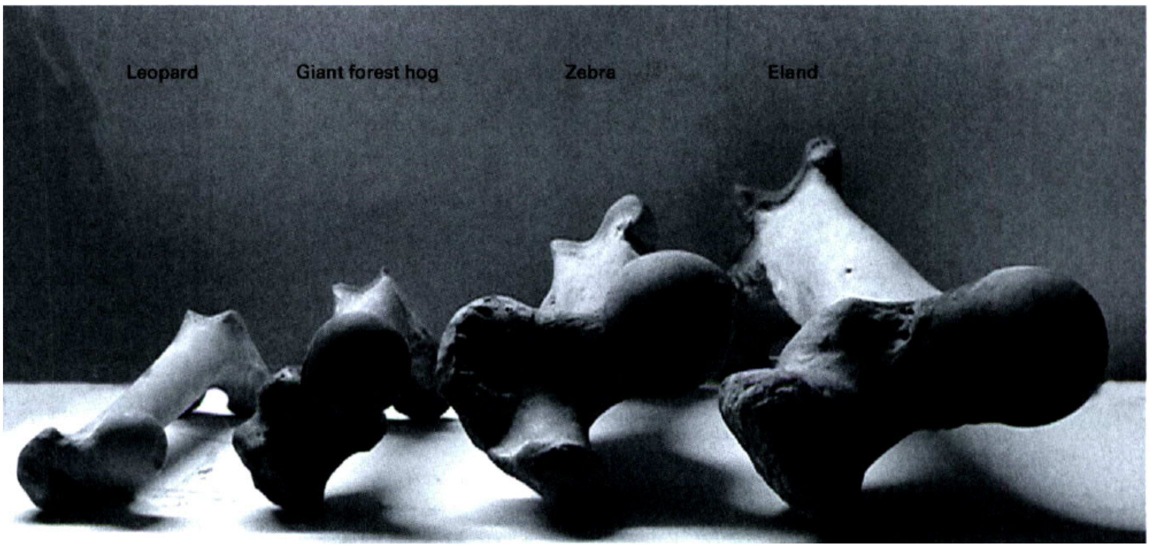

Figure 3 Femoral torsion between leopard, giant forest hog, zebra and eland (Tayton, 2007)

Development of femoral torsion in humans

Femoral torsion is a normal physiological development in human. However it was hyphothesis that femoral torsion can change due to external stresses. Femoral torsion occurs at certain periods during both foetal and postnatal life. Femoral torsion is first identifiable at seven weeks gestation [23] and reported to be in retrotorsion with an angle at about -10º.[21] The range of femoral torsion gradually increases with gestational age to become antetorsion and is reported to be 0º at the end of the first trimester, [24] 12º at just after four months gestation and 24.4º at birth.[21] Femoral torsion was found to continuously decrease throughout childhood and adolescence at around 1.5 º per year [25]until it stabilises at puberty/adulthood. [26]

The gradual rotation from conception through to adulthood, when the femoral torsion angle of about 12º is reached, [21] is theorised to be induced by several factors. First by the flexed position of the embryo and foetus in intrauterine life when the neck of the femur rotates with respect to the condyles. Second, by the acute flexion of the hip and pressure of the uterine wall on the knee causing the neck to rotate on the shaft, forcing medial rotation of the shaft therefore antetorsion. Finally by the pull of the lateral rotators of the femur (gluteus maxiums, posterior aspect of gluteus medius), capsular restrictions and weight of the body at birth through to standing and walking. Gradual stresses imposed from birth to walking is believed to rectify the range of femoral torsion from -10º to 12º. [21, 27]

Although the development of the torsion in the femur is influenced by physiological factors which start in intrauterine life, the underlying causes and the exact mechanism of torsion development remain obscure.[28] Other external factors imposed after birth up to adulthood such as muscle and ligament stresses may contribute to the further development of torsion.

Bone is one of the most plastic tissues in the body, therefore its external form and internal architecture can change due to stresses and strains to which it is subjected during life. [29] Ridges and tubercles in the bones are produced by the attachments of muscles and other structures, and conspicuous ridges on the surface of bones owe their origin to tension by muscles and ligaments. Unlike during the embryonic development, tubercles and tuberosities are formed in direct response to the pull of tendons or ligaments [30] therefore it can be reasonable to suggest that torsion in a long bone occurs along its shaft by the pull of muscles and ligaments that are attached to the proximal and distal ends.

The muscles performing hip functions are mainly attached to the lesser trochanter, the greater trochanter, the shaft and the condyles (Figure 4). Therefore, it can be speculated that muscle mechanics during development and while performing activities contribute the amount of torsion occurring in the shaft as opposed to the neck of the femur. Dance has been suggested as one activity as ballet dancers perform with their lower limbs in external rotation (turnout). External rotation of the hip has been shown to be influenced by greater femoral antetorsion as well as by the soft tissue structures surrounding the joint. [31-33] Hamilton et al (1992) suggested that female dancers with greater range of hip external rotation also have less femoral torsion [34] therefore allowing for better turnout. Based on this wisdom, it is theorised that dancers would benefit from having less femoral torsion which will result in greater range of hip external rotation or turnout. Cultural and habitual factors like squatting have also been proposed to affect the amount of femoral torsion [35] due to the similarity between the squatting position and the intrauterine flexed position of the foetus.

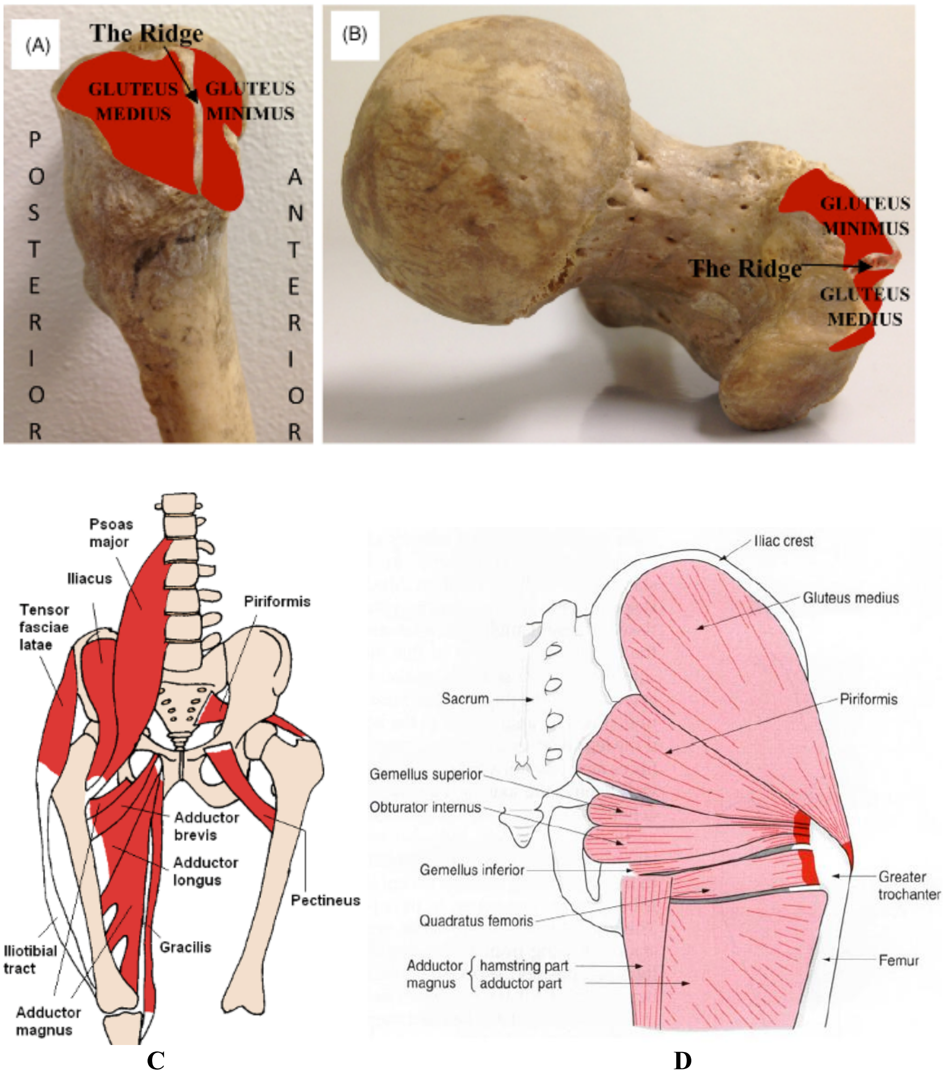

Figure 4 Montage picture of muscles performing hip movement, A & B schematic presentation of muscle attachment on dried bone, C anterior view of hip muscle and D posterior view of hip muscle
(Source: A & B are Candidiate's own work,
C https://code.google.com/p/ahuman/wiki/HumanNervesSpinalThigh and
D http://en.wikipedia.org/wiki/Muscles_of_the_hip)

Torsion and injury: what is already known?

Investigations of the effect of femortal torsion on injury have mainly focussed on hip pathology. [18, 36-38] These pathologies include hip dysplasia [36, 37], congenital dislocation[18] and Legg-Calves-Perthes.[38] Femoral torsion does not appear to have been investigated as a contributing factor to a change of alignment distal to the hip which may increase the risk of injury to the lower kinetic chain in healthy populations or those performing specific activity like dancers.

In the upper limb, the association between torsion and injury have been determined. Excessive range of humeral external rotation as a result of humeral retrotorsion has been found to be a protective mechanism for throwing injuries.[39]

In the lower limb, it has been found that excessive femoral antetorsion is associated with a reduced range of hip external rotation while femoral retrotorsion is associated with an increased range of hip external rotation.[5, 8, 40] There is a corresponding increase or decrease in internal rotation rather than a change in overall hip rotation range. [41] This asymmetrical range of hip rotation may induce capsuloligamentous injury in addition to mechanical disruption of articular structures and shortening of associated muscles.[42] The asymmetry in hip range due to either excessive femoral antetorsion or retrotorsion has the potential to overload the hip or joints lower in the kinetic chain, and is thought to lead to injury. People participating in activities that requires frequent performance of forceful hip external rotation, like dancers, will be highly affected by this situation. The inability of the hip to produce maximum possible range required for external rotation (due to excessive antetorsion) will require compensation by other structures of the lower limb to achieve the desired turnout. Prolonged mechanical overloading imposed on these structures is proposed to be a main factor in distal dance injury. [43]

To date, there is little evidence regarding the contribution of femoral torsion, or other hip factors, to lower limb injury. Therefore, a systematic review was undertaken and is presented in Chapter 2.

Methods of measurement of femoral torsion

Quantifying femoral torsion is important for the accurate placement of implants in total hip arthroplasty[22] therefore, a variety of methods have been described to measure femoral torsion. Methods of measuring femoral torsion both in-vitro and in-vivo have evolved from direct mechanical measurement [44] to the use of; fluoroscopy (1930s),[45] axial and biplanar (1950),[46, 47] computerized tomography (CT) (1950s to 1970s),[48-50] real-time ultrasound (1980s) [51, 52] and Magnetic Resonance Imaging (MRI) (1990s).[53, 54]

Cadaveric (in-vitro) measurement of femoral torsion

The earliest recorded work measuring femoral torsion appears to have occurred in 1878 by a German-Polish surgeon, Jan Mikulicz. He investigated torsion in dried femora from specimens of adult bones.[55] In 1924, Ingalls [56] measured femoral torsion using a Stativgoniometer (a goniometer attached to a tripod). Femoral torsion of a dry bone was measured by placing the bone on spring clamp against a vertical board, adjusted so that the axis of the shaft was horizontal. Two points were marked on the bones, one on the centre of the head and one on the greater trochanter. The line joining these two points represented the axis of the neck. A horizontal shelf placed exactly at the right angles to the vertical board held the Stativgoniometer. On this horizontal shelf lies the posterior condyles of the femur. The angle of torsion was quantified by the angle subtended by the line representing the axis of the neck and the horizontal shelf.

The method developed by Mikulicz was then adapted and modified by a method devised by Kingsley and Olmstead which is claimed to be the most exact method of cadaveric measurement of femoral torsion.[24] Kingsley and Olmstead used a similar method to Mikulicz, but excluded the head of femur as they found 68.7% of the femora had a displaced head therefore this was not used to aid in determining the true angle of torsion. The neck axis was determined using a line connecting two exact centre points dividing the anterior and posterior aspect of the neck when viewed from above (Figure 5A). The two points on the centre of the neck were identified using a height gauge (Figure 5B, 5C & 5D). Most of the latter studies on femoral torsion were undertaken based on the method developed by Kingsley and Olmstead.

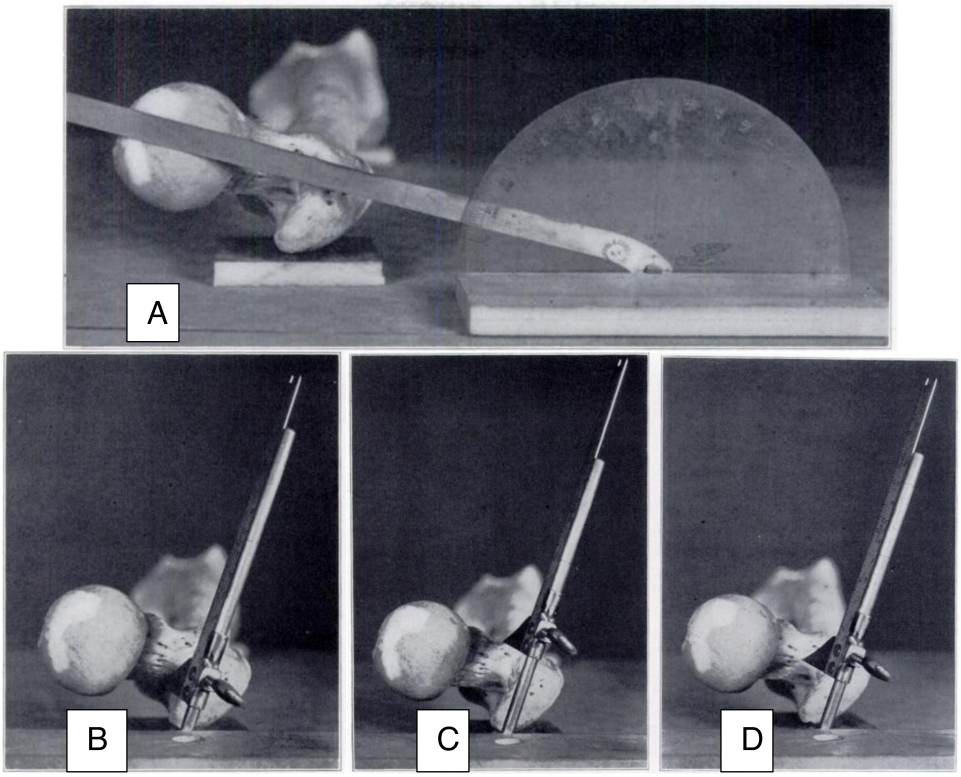

Figure 5 Image montage of the method of measuring femoral antetorsion with a gouge used to identify the points on the neck of femur; A measuring femoral antetorsion, B posterior border of the mid neck, C superior border of the neck and D the mid point (Kingsley & Olmstead, 1949)

In-vivo measurement of femoral torsion

Measuring femoral torsion directly is ideal in dry bones but obviously presents difficulties in living persons therefore clinical measurement and imaging methods are required. The broad availability of radiographic instruments in the early to mid 20th century facilitated the development of new methods to measure femoral torsion in-vivo. The three most common methods described by the literature are; the bi-planar method, axial method, and fluoroscopic method.

The fluoroscopic method was first described by Rogers in 1931.[45] Using this method, the hip was observed through a fluoroscope. Femoral torsion was quantified in two different positions. First, the patient was positioned in prone, hip neutral and knee flexed at 90º with the shank perpendicular to the table. Femoral torsion was quantified as the angle subtended between the anterior aspect of the head-neck-greater trochanter and the table. Secondly, with the patient in the same position, the shank was rotated inwards towards the midline of the body until the anterior aspect of the head-neck-greater trochanter was perpendicular to the table. Femoral torsion was quantified as the angle subtended by the medial aspect of the shank and the table (Figure 6). The author concluded that the second position could be employed to clinically determine femoral torsion.

Rogers et al (1931) used radiography as a method of measuring femoral torsion, and concluded that femoral torsion could be clinically quantified by determination of the relative positions of the greater trochanter and the transverse axis of the femoral condyles.[45]

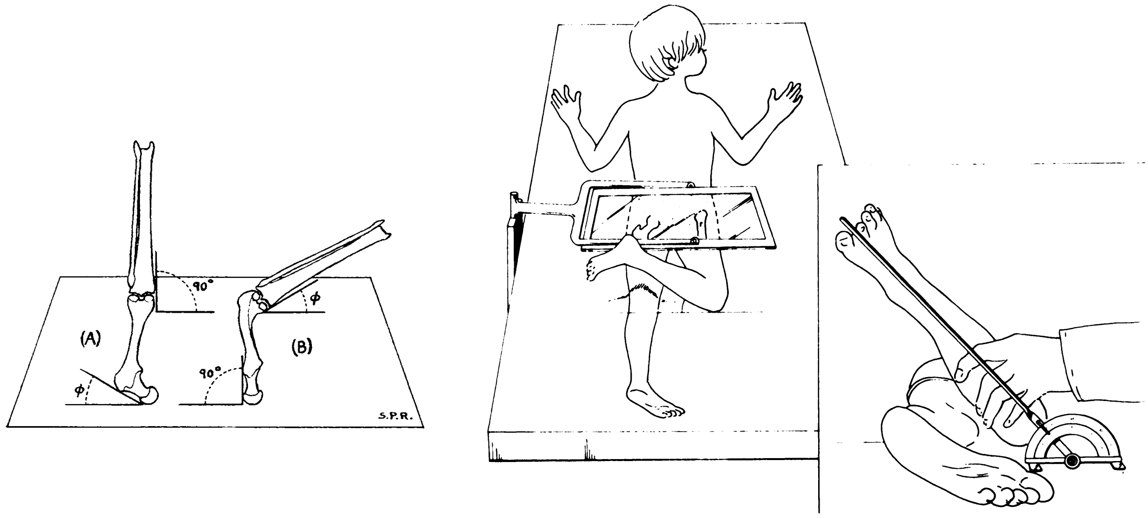

Figure 6 Drawing depicting Roger’s method of measuring femoral torsion

Dunn (1952) developed the axial method for measuring femoral torsion. [46] This method placed the participant in a supine position with 90º flexion both at the hip and the knees (Figure 7). The radiographic ray was directly beamed through the longitudinally positioned femur so that the femoral condyles appeared to be superimposed on the neck. The angle of femoral torsion was obtained by the angle between the transcondylar plane and the neck.[46] This was a much more straight forward method where femoral torsion was directly measured using a single radiograph taken along the axis of femur, giving an overlapping view of both proximal and distal ends.

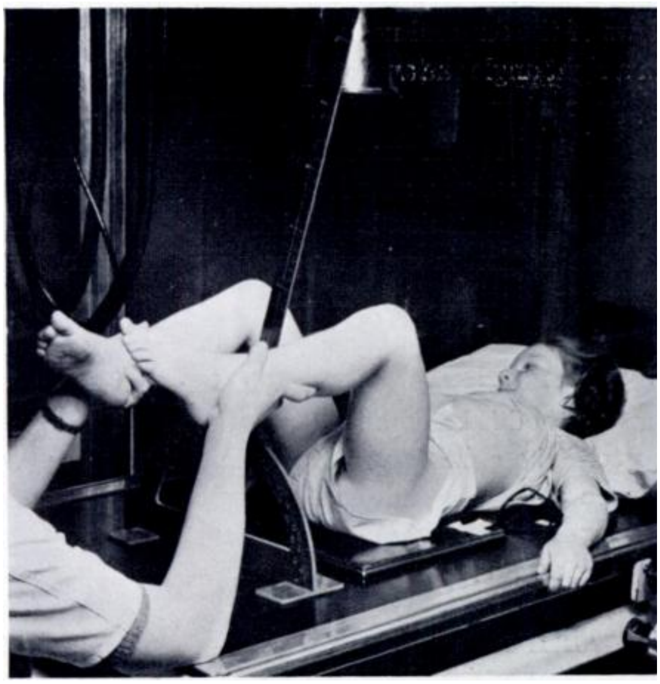

Figure 7 Femoral torsion measurement adapted from Dunn (1952)

Studies measuring femoral torsion using the bi-planar method were mostly based on the eminent study by Ryder and Crane (1953). [47] Quantifying femoral torsion using this method required plain-film imaging of patients twice; one in a normal anterior-posterior (AP) position in supine and one with the patient's legs held with a support frame that maintains the hip at 30º abduction with knees flexed at 90º. The angle subtended by the neck-head and the shaft (the inclination angle) was computed on the AP positioned film (projected inclination), and the angle subtended by lines representing the axis of the neck and the transcondylar line was computed on the film taken with the hips in abduction (projected anteversion). True angle of torsion was quantified using the conversion table (Figure 8) [47].

projected inclination \ projected anteversion	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
80	0	3	7	12	16	20	24	29	33	38	43	47	53	59	65	71	77	84	
90	0	4	9	13	17	22	27	31	36	41	46	51	56	62	67	73	79	84	
95	0	5	9	14	18	23	28	32	37	42	47	52	58	63	68	74	79	85	
100	0	5	10	14	19	24	29	34	39	44	49	54	59	64	69	74	80	85	90
105	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
110	0	5	10	16	21	26	31	36	41	46	51	56	61	66	71	76	80	85	90
115	0	5	11	16	22	27	32	38	43	48	53	57	62	67	72	76	81	85	90
120	0	6	11	17	23	28	34	39	44	49	54	59	63	68	72	77	81	86	90
125	0	6	12	18	24	30	35	41	46	51	56	60	65	69	73	78	82	86	90
130	0	6	13	19	25	31	37	42	47	52	57	62	66	70	74	78	82	86	90
135	0	7	14	20	27	33	38	44	48	54	58	63	67	71	75	79	83	86	90
140	0	7	14	21	28	34	40	46	50	56	60	64	68	72	76	80	83	87	90
145	0	8	16	23	30	36	42	48	53	58	62	66	70	74	77	80	84	87	90
150	0	9	17	25	32	39	45	50	55	60	64	68	72	75	78	81	84	87	90
155	0	10	19	27	35	42	48	54	58	63	67	70	73	77	79	82	85	87	90
160	0	11	22	31	39	46	52	58	62	65	70	73	76	78	81	83	86	88	90
165	0	13	26	36	45	52	57	62	66	70	73	76	78	80	82	84	86	88	90
170	0	18	33	45	53	60	65	69	72	75	77	79	81	83	84	86	87	89	90
175	0	29	48	59	67	71	75	77	79	81	82	84	85	86	87	88	88	89	90
180	0	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90

ANTEVERSION

Figure 8 Conversion table from inclination angle to femoral torsion angle (Ryder-Crane, 1953)

Computed tomography (CT) was developed from sophisticated radiographic methods. CT replaced bi-planar radiography in the 1970s and became the "Gold Standard" for the accurate imaging and measurement of femoral torsion.[53] Measuring femoral torsion using CT was first mentioned in the literature by Weiner et al, 1978. [48] However, its usage in measuring femoral torsion only became extensive in the late 80's. CT provides the opportunity to visualise both the cross-sectional and three dimensional anatomy of human tissue and is especially suited to imaging bones. CT imaging has therefore been advocated to determine femoral torsion in living subjects by several authorities.[57-60]

Techniques for the calculation of femoral torsion using CT vary, but the method described by Murphy et al (1987) is often used with slight variations.[61-63] Murphy designed a new CT method in measuring femoral torsion and compared the accuracy of the newly designed method to the then currently practiced CT method.[50] Murphy's technique was based on the strict geometrical reconstruction of the angle of antetorsion and involved capturing three images; two proximal and one distal with the participant positioned with the long axis of the femoral neck parallel to the long axis of the scanner.[49] One image defines the location of the centre of the femoral head, the second image defines the base of femoral neck and the third image defines the distal femoral condylar axis (Figure 9). Billing's method involves capturing only one image of the axis of proximal femur. This method however was found inaccurate due to different shapes of the femur.[49] Murphy concluded that the method practised by Billing (1954) consistently underestimated antetorsion and the new method was recommended as it was more accurate and reproducible.

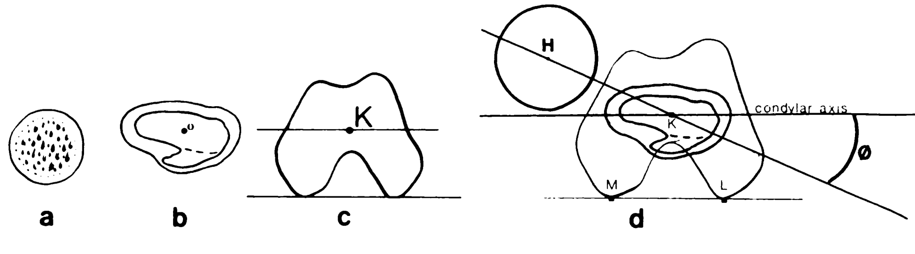

Figure 9 Quantifying femoral torsion using CT picture adapted from Murphy et al (1987). The patients is positioned in the scanner such that the long axis of the femur is parallel to the long axis of the scanner. (a) defines the location of the centre of femoral head H. The second image (b) defines the centre of the base of the femoral neck O. The third image (c) defines the condylar axis. The angle in the transverse plane between the intersection of the plane of antetorsion (line HO) and the condylar plane defines the angle of antetorsion V (d).

The use of ultrasonography to measure femoral torsion was first described by Moulton and Upadhyay in the early 1980s.[51] Ultrasound was used to measure femoral torsion in-vivo and in-vitro. This technique required imaging the proximal femur; the neck and head, and distal femur; the condyles of a patient positioned in neutral leg rotation. The ultrasound transducer was held horizontally during imaging both the proximal and distal femur. The line connecting the condyles, the intercondylar line was used as the reference line. Through superimposing the two images, the difference between the line connecting the superior border of the greater trochanter, neck and head of the femur and the intercondylar line was quantified as the angle of torsion (Figure 10).

This method was employed until Terjesen and colleagues developed a simpler method which did not require images to be superimposed. [64] Femoral torsion was measured with the patient supine and knees flexed at 90º at the edge of the table. The ultrasound head was placed over the neck of the femur and tilted around the anterior thigh until the image of a line representing the superior border of the head of the femur and greater trochanter appeared on the screen. Once this image appeared on the screen, the transducer was then tilted again until the line of the superior border of the greater trochanter, neck and head of the femur was horizontal on the screen and the tilted angle displayed by the inclinometer attached on the transducers was the angle of torsion.[64] Later research describing femoral torsion measured using ultrasound were based on this method.[52, 65-67]

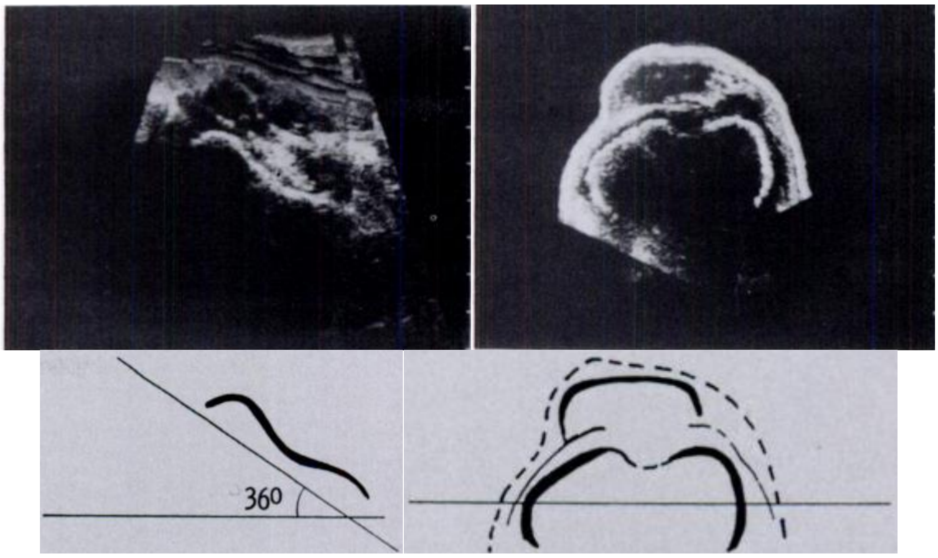

Figure 10 Montage image from Moulton and Upadhyay (1987). Tope left showing the ultrasound image of the femoral neck axis. Top right showing the image of the condyles of the knee. Remaining two images show the schematic image of the proximal and the distal axes and how femoral torsion was computed using a superimposition method

In the late 20th century, the use of magnetic resonance imaging (MRI) for musculoskeletal disorders rapidly increased in popularity as a new radiation-free accurate technique for musculoskeletal and anatomical imaging. Therefore MRI became the new "Gold Standard" specifically for the assessment of femoral torsion.[68] MRI was first mentioned in the literature as method for measuring femoral torsion in 1995 by Guenther and colleagues using alpha and beta angles.[54] The alpha angle was described as the angle made by the axis of proximal femur and the horizontal reference line while the beta angle was described as the angle between the line through the centre of femoral condyles and the horizontal reference line (Figure 11). Angle of femoral torsion was quantified by subtracting the beta from the alpha angle. Guenther et al (1995) [54] concluded that the use of MRI improved the visualisation of the proximal axis of the femur since the method involves taking six slices of 10mm apart. A single image which showed the centre of the head and neck (allowing visualisation of the true neck axis) was then selected.

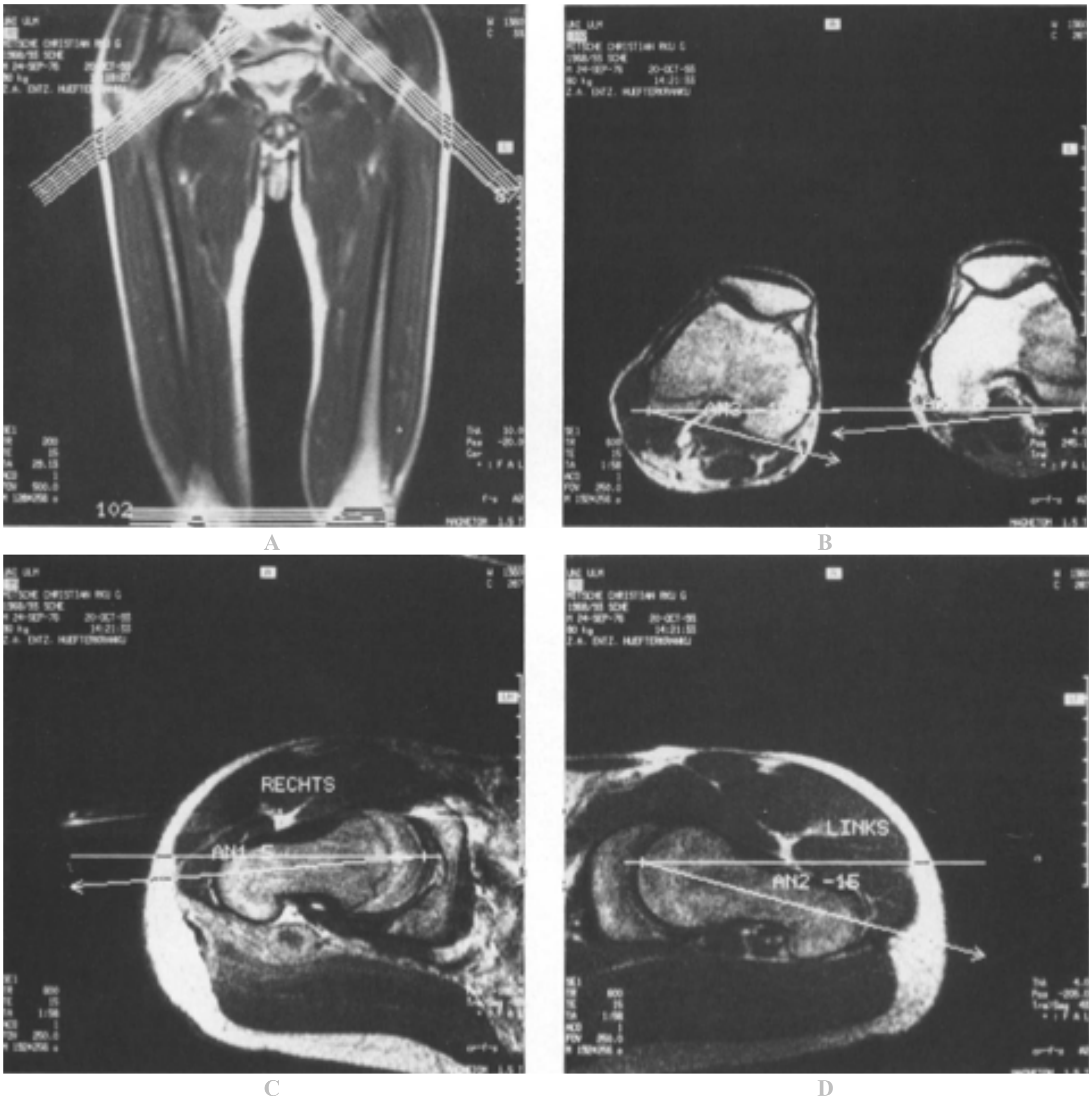

Figure 11 MRI determination of femoral torsion. A; proximal axis – femoral neck axis, B; distal axis – posterior condyles, C; image of the proximal axis of the right hip viewed from the top, D; image of the proximal axis of the left hip viewed from the top (Guenter et al, 1995)[54]

A concern in relation to both radiography and CT is the level of radiation dosage to the genitalia area. Sullivan et al (1982) calculated a midline pelvic radiation dosage of 107 millirads per cut for CT and 20 millirads for radiography.[69] Ruby et al (1979) estimated levels between 35 milliroentgens despite using gonad shields and three roentgens for the radiographic techniques.[70] According to Shapiro (1981), one roentgen is equal to 0.96 rad in tissue.[71] As concluded by Sullivan et al (1982), this level of radiation is relatively high therefore its use in children should be highly limited and impractical in clinical use.[72, 73] In addition to the increased radiation, CT is also not freely available.[74]

Problems with current methods of measuring femoral torsion

There are several problems with the measurement methods presented above. Defining the proximal axis through the head of femur through to the neck presents several difficulties depending on the method employed. Many methods quantify the proximal axis as the line connecting the centre of the head and the centre of the neck. Accurate location of the centre of the head can be difficult to determine because the head of femur is not normally located at the centre of the neck as found by Kingsley and Olmstead.[24] Sixty nine percent of the heads of femur were displaced either anteriorly or posteriorly therefore were not used to aid in determining the proximal axis in their study.

Determining femoral torsion by clinical examination alone was discussed as early as 1936 by Krida et al (1936) however the method was universally condemned as it was incompletely described.[44] Netter, as his doctoral thesis in 1940, developed a clinical method of estimating femoral torsion by palpation of the maximum lateral prominence of the greater trochanter identified by rotating the hip internally and externally in supine position with the knee bent the over the edge of the bed. Femoral torsion was represented by the angle of tibia movement from the starting position. Five to 10º of variance within intrarater and interrater reliability was found. The clinical method was the only early method used to measure femoral torsion that does not radiate the patients. However, use of the measure is questionable since there is no evidence reporting its reliability and validity.

The use of ultrasound is non invasive and eliminates the risk of radiation however is highly dependent on the user,[75] therefore inconsistent imaging technique may result in inaccurate determination of femoral torsion. To date, measuring femoral torsion involves the neck and the head of femur as the reference line on the proximal femur, and posterior border of the condyles as the reference line on the distal femur.[52, 76, 77] Some researchers also used the line connecting the condyles as a reference line.[51] Identifying the line connecting the neck and the head of the femur can be challenging and almost impossible in people with high body mass index (BMI) and therefore may restrict the usage of the methods utilising this landmark to only people with low BMI.

Femoral torsion and proprioception

Torsion in the humerus of the upper limb has been shown to influence proprioceptive acuity of the shoulder in the throwing athlete. [78] However the same relationship has not been identified in the lower limb. The word proprioception has been incorrectly used synonymously and interchangeably with kinesthesia, joint position sense, somatosensation balance and reflexive joint stability.[79] Sherrington (1947) [80] used proprioception to reference the afferent information arising from proprioceptors located in the proprioceptive field, being used for regulation of postural control, joint stability, and muscles senses.[80] In addition, Sherrington also described four submodalities of muscle senses; (i) posture, (ii) passive movement, (iii) active movement and (iv) resistance to movement. These submodalities correspond to contemporary terms of joint position sense, kinesthesia and sense of heaviness. Proprioception contributes to the motor programming for neuromuscular control required for precision movements and also contributes to muscle reflexes, providing dynamic joint stability.[81]

Kinesthesia and joint position sense (JPS) are the submodalities commonly used to test proprioception. Kinesthesia tests the sense of discrete movement of a joint using a specific speed. Joint position sense tests the person's ability to reproduce joint position at different angles.[82] Neither of these methods is superior to the other however, they might measure different components of proprioception rather than being interchangeable. [83]

Proprioceptive acuity is a measure of a person's ability to perceive two movements of different magnitudes as distinct from each other. Consequently, this measure is the smallest difference between two movements to be reliably identified. The smaller the difference, or error, when reproducing a joint position, the better the proprioceptive acuity.

In the hip, research on proprioception is currently focused on proprioceptive acuity in people with total hip replacement.[84-86] Proprioception of the hip was found to be largely intact despite hip arthroplasty therefore proprioception was suggested not to be dependent on the joint capsule. [85, 86] However, it is still plausible that the less than optimal biomechanics of excessive femoral torsion (ante or retro) would affect the sensory input to and motor output from the hip as altered tension in passive soft-tissue restraints (joint capsules and ligaments) and altered length/tension relationships of active restraints (musculature) may affect afferent input from mechanoreceptors in these structures as suggested in Gandevia, 2002. [87]

A few studies have found that joint-position sense at the hip is preserved after capsulectomey and articular surface replacement. [84, 86, 88] This is believed to be due to the discharge of extracapsular (ligament, tendon, muscle and skin) afferent receptors. [88] The existence of these extracapsular components and their contribution to proprioception was also acknowledged by Goodwin et al and Provins. [89, 90] Therefore, despite capsulectomy and articular surface replacement during hip arthoplasty, hip proprioception is preserved because it is believed that proprioception of the hip is contributed to by afferent receptors located outside the joint capsule.

The orthopaedic surgeon aims to locate the prosthesis to mimic the patient's natural femoral torsion to minimise complications. Since proprioception of the hip relies on extracapsular components [87], constant stretching of these components as a result of excessive torsion (ante or retro) may have an impact on the proprioceptive acuity of a joint.

In the long bone, torsion that changes over time is believed to alter tension in the joint capsule as well as in the structures outside the joint capsule; ligaments, tendons and muscle. This scenario is evident in the study by Whiteley et al, 2008 who found that a retrotorted humerus was associated with higher scores of proprioceptive acuity in the throwing athlete.

From these findings, the authors believed that better proprioceptive acuity with humeral retrotorsion could be due to Magil's concept of 'automaticity'. Due to the altered range of motion; in this case a greater range of shoulder external rotation, less cognitive processing was required during the performance of motor tasks, i.e.; the cocking phase in throwing. The available cognition that is not used to perform cognitive processing due to the exploitation of the biomechanical properties would then be allocated elsewhere. [91]

In the upper limb increased range of shoulder external rotation as a result of retrotorted humerus has been found to improve proprioceptive acuity in the young throwing athlete.[78] An association between biomechanical aspects of the muscular skeletal system on the cortical demand associated with motor control has been proposed to justify this relationship.[92] To date, there is no standardised definition for cortical capacity. Cortical capacity demand refers to the increased demand of the function of the cerebral cortex to process information (encoding and decoding) and produce action based on the information processed. [93] Exploitation of the biomechanical properties of the upper limb, in this case retrotorsion of the humerus may reduce the cortical processing demand therefore increasing the efficacy of movement control in the throwing athlete.

In the hip, studies have also found that femoral retrotorsion is associated with increased range of hip external rotation [8] and excessive femoral antetorsion has been associated with increased range of hip internal rotation and reduced range of hip external rotation. [5, 8, 40] If the same analogy in the upper limb applies to the lower limb, proprioceptive acuity score of the hip joint should be better in a femur that is retrotorted; which may account for better proprioceptive acuity in the hip however, this theory has never been investigated. The study presented as Chapter 4 of this thesis was conducted to explore this relationship.

Dancers and femoral torsion

Dancers require complete control of all body joints and the hip joint is one focal point that can affect dancers' technical appearance.[31] Despite its structural predisposition for stability, the hip joint allows a surprising degree of motion that dancers strive to enhance to a degree rarely seen in other sports. A great deal of emphasis is placed on hip positions, particularly external rotation and abduction. This emphasis is not only present in classical ballet but also in many forms of dance throughout the world. Indian dance, used primarily for religious purposes, includes a significant gesturing of the hands and arms as well as positioning of the hip, knees and feet. In Western cultures, an early indication of a student's aptitude for classical dance is a good turnout (Figure 12).

Turnout, describes the external rotation position of the legs. "Ideal" turnout has traditionally been described as 180º of external rotation of both legs combined.[94] To maximise this potential range without creating injuries, 70º of passive hip external rotation is thought to be required unilaterally with the remaining 40º achieved at joints distal to the hip.[95] The ability to perform turnout movement fully is influenced by bony anatomy, ligamentous laxity, and muscle strength.[43] Bony factors include the orientation of the acetabular facet, the angle of inclination of the femur and femoral antetorsion.[96] Due to the demand of producing significant range of turnout in dancers, dancers without sufficient range of hip external rotation (maybe due to excessive femoral antetorsion) may have greater risk of injury to the lower limb as they attempt to force turnout by gaining additional external rotation from the joints distal to the hip; the knee and the ankle.[43]

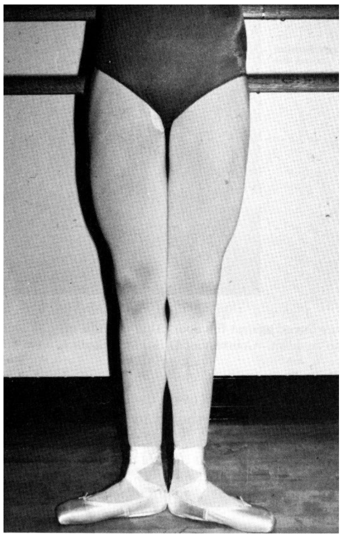

Figure 12 Turnout in classical ballet

Studies performed on elite dancers have found turnout is greater in female dancers than their male counterparts.[34, 40, 97-100] Some of these studies found total range of motion in female dancers is only slightly greater than non-dancers.[97] However, dancers have significantly greater external rotation of the hip which is accompanied by an equal decrease in internal rotation at hip to accommodate a similar total range of motion.[34, 97] This indicates that there may be a rotational asymmetry within the dancers' hips which allows greater external rotation at the expense of internal rotation.

Despite being theorised that dance training at young age (before 11 years) can affect the amount of femoral torsion,[8] this does not happen to every dancer, or dancers who begin training at a later age. [101] Femoral torsion in dancers who commenced dancing activity at a younger age is believed to be less (femoral retrotorsion) due to the amount of plasticity that is still available in the femoral neck. Working with turnout from an early age may change the stresses placed on the femur therefore resulting in a change in torsion (retrotorsion). As femoral retrotorsion is associated with a greater angle of hip external rotation, dancers with femoral retrotorsion should have the advantage of performing turnout mostly from the hip with very minimal involvement of the joints distal to the hip. Dancers who do not have femoral retrotorsion (excessive femoral antetorion) may therefore be prone to producing "ideal" turnout by compensating at the joints distal to the hip; the knee and ankle therefore increasing the likelihood of developing injuries [43].

Prevalence of lower limb musculoskeletal injuries in dancers is 60% to 80%[102, 103] with the most affected areas being the knee, the ankle and the foot. Injuries to these anatomical sites could be due to the compensatory strategies adopted for years in producing turnout however, no study has looked at this relationship. While it is unclear whether these are acute, overuse injuries or both, the most affected areas are reported as the knee, ankle and foot.

In the upper limb humeral retrotorsion is found to be associated with greater range of external rotation of the shoulder and is therefore a skeletal advantage in throwers in reducing the risk of injury. If the same analogy occurs in the lower limb, femoral retrotorsion should be a skeletal advantage in dancers since femoral retrotorsion has been associated with greater range of hip external rotation. Therefore, femoral retrotorsion in dancers may also be a possible factor in reducing the risk of lower limb injury since performing ideal turnout can occur with minimal compensation of the structures distal to the hip.

Femoral shaft torsion; the definition and method to be used in this thesis.

In this thesis, the contribution of femoral torsion measured at the shaft is investigated and will be referred to as femoral shaft torsion. Femoral shaft torsion will be measured with a newly developed real-time ultrasound protocol using different landmarks than described by the conventional radiological studies as this new method measures torsion in the shaft of the femur and not the head-neck of the femur. Therefore, for the purpose of this thesis, femoral shaft torsion is defined as torsion that occurs along the shaft of the femur, computed through the angle made by the condyles when the ridge of the greater trochanter is more superficial laterally. Femoral shaft torsion will be categorized as medial shaft torsion and lateral shaft torsion. In this thesis, the contribution of_femoral torsion measured at the shaft is investigated and will therefore be referred to as femoral shaft torsion. Detailed information about the development of the new method is described in Chapter 3. In Chapter 4 and 5 the femoral torsion is referred to either medial shaft torsion (femoral antetorsion) and lateral shaft torsion (femoral retotorsion) to aid the reader.

Aim of the thesis

This thesis describes the development of a new reliable ultrasound method to measure femoral shaft torsion in the clinic. The method will enable clinicians to identify the degree of femoral shaft torsion in patients without the need for expensive, time consuming imaging techniques. The importance of the relationship of femoral shaft torsion to lower limb injury and proprioception can then be easily investigated in community populations. In addition, the possibility of proxy measures, not requiring the use of a real-time ultrasound machine, were investigated. This thesis describes the development of a new method to measure femoral shaft torsion that will enable clinicians to identify the degree of femoral shaft torsion in patients. Therefore, the aims of this thesis were:

1. To systematically review the literature for all types of hip characteristics, particularly femoral torsion, in causing lower limb injury (Chapter 2).
2. To describe a new method of measuring femoral shaft torsion using real-time ultrasound and report the reliability of this new method (Chapter 3).
3. To investigate the relationship of femoral shaft torsion and hip proprioceptive acuity (Chapter 4).
4. To investigate the difference in range of femoral shaft torsion between injured and non-injured dancers. A secondary aim was to investigate whether there was a relationship between femoral shaft torsion and other hip measures (Chapter 5).

This thesis was prepared in the format of 'thesis by publication' therefore the chapters are presented based on the format required by the journal to which the work has been submitted. The guidelines for authors for all submitted works are included in the Appendices. Chapter 3 is presented in the published format. Chapters 4 & 5 are presented in the format required by the journals. Each chapter of the thesis has its own reference list, however referencing is presented in a standardised format throughout the thesis to aid the reader. The tables and figures are also placed at the relevant sections of the text to aid the reader.

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Faculty of Health Sciences

Publication Statement

As co-authors of the paper "Do hip structure, range of motion and strength predict pain and pathology distal to the hip?: A systematic review" we have confirmed that Eliza Hafiz made the following contributions:

- concept and design of the research proposal
- data collection
- analysis and interpretation of the findings
- drafting and revising the paper and critical appraisal of content

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Leslie Nicholson....L Nicholson........................ Date:..11/8/14......

Kathryn Refshauge.....K. Refshauge..... Date:....7/8/14...

CHAPTER 2

Do hip structure, range of motion and strength predict pain and pathology distal to the hip?: A systematic review

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ABSTRACT

Purpose: Various hip characteristics are hypothesised to predispose to injury distal to the hip, but this is unproven due to the paucity of prospective studies. Understanding this relationship is beneficial for intervention, selection and injury prevention. Therefore the aim of this review was to determine whether abnormal hip characteristics are associated with distal pain and injury.

Methods: Studies were identified using Medline, PubMed, CINAHL, Web of Science, Embase and SportDiscus databases from the earliest date through August 2014, plus hand searching. Inclusion criteria were established a priori and included studies underwent quality assessment by two independent reviewers.

Results: Seven studies met the inclusion criteria and five of the seven suggested that abnormal hip characteristics can increase the risk of lower limb injury. Greater hip external rotation range predisposes to lower limb stress fracture (RR = 1.8), tibial stress fracture (RR = 2.0) and femoral stress fracture (RR = 2.4). Reduced hip internal rotation range was found to protect adolescent runners from medial tibial stress syndrome (OR=0.91, 95% CI 0.85-0.99). Stronger hip external rotators (RR=4.02, 95% CI 1.03-15.72) and abductors (OR=5.35, 95% CI 1.46-19.53) predispose to patellofemoral pain (PFP) in naval recruits and runners respectively.

Conclusion: Greater range of hip external rotation and greater hip external rotator and abductor strength were risk factors for developing lower limb injury, while decreased hip internal rotation was protective. However the strength of the findings are unknown or imprecise, the investigated populations varied, and the results should be accepted with caution.

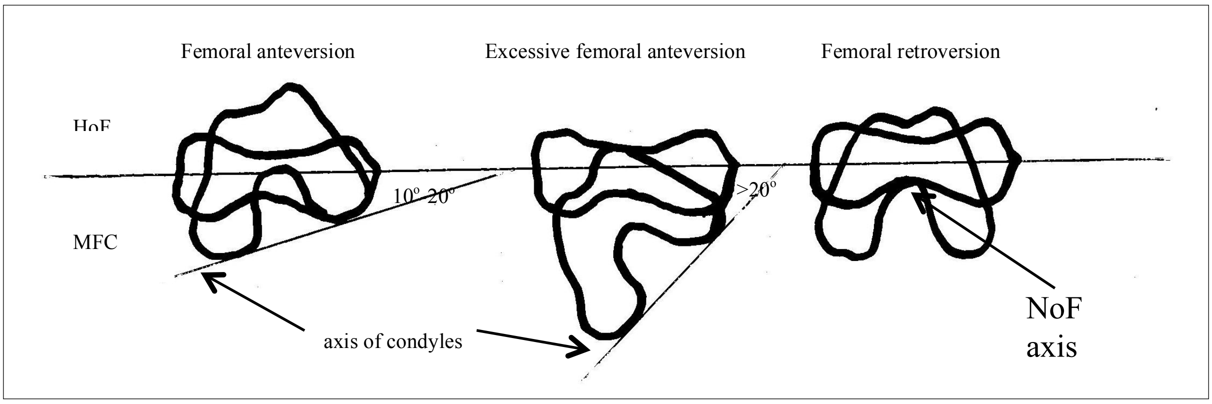
Key Words: Hip range of motion, strength, kinetics, kinematics, ACL injury, patellofemoral pain

Level of Evidence: Systematic review with Level-I studies

INTRODUCTION

A healthy hip is pain-free and has adequate range of motion, muscular control and strength commensurate with its function,[41] however altered hip states may be associated with injury both locally and distal to the hip itself. Several hip characteristics: femoral torsion,[104, 105] range of motion,[106] strength,[107, 108] stability and hypermobility [109-111] have been found to be associated with lower limb pathologies. Alterations in hip kinetics and kinematics have also been associated with hip[112-114] as well as knee joint pathology.[115, 116] Injury and trauma to the hip may affect lower limb kinetics and kinematics potentially causing pain and injury to distal structures.[117-119] Although significant associations have been found between hip characteristics and lower limb pathology, the retrospective design of these studies render them unable to identify causality.

In retrospective studies, femoral torsion, also known as femoral antetorsion (Figure 1), has been shown to have an association with lower limb injury.[104, 105] Both excessive ante and retrotorsion have been associated with lower limb pathologies. Excessive femoral antetorsion (>15 degrees) has been associated with anterior knee pain in adults,[105, 120] while femoral retrotorsion (<10 degrees) was associated with knee arthritis. Knee arthritis was hypothesised to be a result of discrepancy between the rotational tolerance of the multiaxial hip joint and that of the biaxial condylar knee joint.[104] An in-vitro study also found a significant increase in contact pressure on the contralateral facet of the patella with femoral antetorsion angles greater than 15 degrees, potentially explaining the association with pain.[120] Femoral torsion has also been shown to cause asymmetry of hip rotational range[5, 6, 104, 105, 121, 122] which could lead to overload and injury distally in the kinetic chain.



HoF: Head of femur; MFC: Medial Femoral Condyle distally; NoF: Neck of femur

Figure 1 Femoral torsion

Reduced hip muscle strength has been shown, in retrospective studies, to be associated with patellofemoral pain,[107, 123, 124] osteoarthritis of the medial tibiofemoral compartment [108] and non-contact ACL injury in soccer players.[125] The authors of one cross-sectional study hypothesised that significant side-to-side disparity in hip abductor strength among female soccer players compared to their male counterparts contributed to the higher prevalence of non-contact ACL injury seen in females.[126]

Identification of risk factors in developing lower limb injury is important in preventing lower limb injury as well as providing optimal management of lower limb injury which includes strategies to address the cause of the injury. To enable such targeted rehabilitation, thereby improving prognosis and the risk of re-injury, identification of hip characteristics that increase the risk of lower limb injury are paramount. Therefore, the aim of this review was to determine whether hip characteristics (femoral torsion, range of motion, strength and functional biomechanics), measured using static or dynamic variables, increased the risk of pain and injury distal to the hip.

METHODS

Identification of studies

Eligible studies were identified through a search without language restrictions of Medline, PubMed, CINAHL, Web of Science, Embase and SportDiscus databases from the earliest date through to August 2014. The search strategy (Appendix 1) was designed by the authors in conjunction with an experienced medical librarian. Hand searching of reference lists of all included studies and relevant reviews was also performed. All identified studies were screened by two independent assessors using the inclusion criteria. A third assessor was consulted for any ambiguity until consensus was reached.

Appendix 1: Search strategy
Database: Medline, Embase, Cinahl

1. exp hip/
2. exp hip injuries/
3. exp groin/
4. exp Torsion Abnormality/
5. exp Torsion, Mechanical/
6. exp Athletic Injuries/
7. exp Hip Joint/
8. exp Femur/
9. exp Rotation/
10. Femur/
11. exp "Range of Motion, Articular"/
12. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
13. causal*.tw.
14. causation*.tw.
15. pred*.tw.
16. risk*.tw.
17. assoc*.tw.
18. exp risk factors/
19. exp Longitudinal Studies/
20. exp Prospective Studies/
21. exp Clinical Trial/
22. exp Prevalence/
23. exp Cohort Studies/
24. exp Randomized Controlled Trials as Topic/
25. rct.tw.
26. 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28
27. exp Leg Injuries/
28. exp Foot Injuries/
29. exp Knee Injuries/
30. exp Athletic Injuries/
31. exp Hip Injuries/
32. injur*.tw.
33. exp Muscle, Skeletal/
34. exp Leg Injuries/ or exp Muscles/ or exp Tendon Injuries/ or exp Athletic Injuries/
35. sprain*.tw.
36. (sprains and strains).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
37. exp Ankle Injuries/
38. exp Posterior Cruciate Ligament/ or exp Ankle Injuries/ or exp Ligaments, Articular/ or exp Knee Injuries/ or exp Knee Joint/ or exp Joint Instability/
39. 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41
40. 12 and 42
41. 29 and 43

Inclusion criteria

As the aim of this review was to investigate whether hip characteristics predict lower limb injury, only prospective studies with objective measurements of hip characteristics and reporting the incidence of injury were included. Hip characteristics included femoral torsion, hip range of motion, hip strength, kinetic and kinematic variables. Lower limb injury included musculoskeletal injuries to bone, muscle, tendon tissue, or injury to the joints of the knee, ankle and foot as diagnosed by a health practitioner.

Methodological quality assessment

Methodological quality of included studies was assessed using the checklist developed by Downs & Black [127] for randomised and non-randomised studies. The original checklist comprises 27 items, but only 16 items were used based upon their applicability for all the included papers (Table 1). In cases where an item was unable to be determined from the paper, two additional classifications were added to the original yes/no classification; (i) unable to identify and (ii) not applicable (N/A). When an item was classified as unable to be determined, a score of 0 was allocated. Two assessors independently assessed the quality of each study with ambiguities resolved through discussion or with a third assessor when agreement could not be reached.

Table 1 Methodological Rating using Modified Downs and Black scale [127]

	Giladi et al (1987) [128]	Giladi et al (1991) [129]	Yagi et al (2013) [130]	Finnoff et al (2011) [131]	Boling et al (2009) [132]	Liederbach et al (2008) [133]	Thjis et al (2011) [134]
Clear aim/hypothesis	1	1	1	1	1	1	1
Outcome measure clearly described	1	1	1	1	1	1	1
Patients characteristics clearly described	1	1	1	1	1	1	1
Main findings clearly described	1	1	1	1	1	1	1
Measures of random variability provided	1	1	1	1	1	1	1
Characteristics of patients lost to follow-up described	1	1	1	1	1	1	1
Actual probability values reported	1	1	1	1	1	1	1
Participants asked to participate representative of entire population	1	1	1	1	1	1	1
Participants prepared to participate representative of entire population	1	1	1	1	1	1	1
Blinding of outcome measure	0	0	0	0	0	0	1
Analysis completed was planned	1	1	1	1	1	1	1
Appropriate analysis	1	1	1	1	1	1	1
Valid and reliable outcome measure	1	1	1	1	1	1	1
Appropriate case control matching	1	1	1	0	1	1	1
Subject in different group recruited over the same period of time	1	1	1	1	1	1	1
Loss of participants to follow-up taken into account	1	1	1	1	1	1	1
Total	15	15	15	14	15	15	15

Data extraction and analysis

Data extraction was undertaken independently by two authors. A third author adjudicated in cases where a consensus was not reached. Data extracted from each included study were age, gender, number of participants, hip characteristics, types of lower limb injury, predictor and other relevant results. Predictor results were reported odds (OR) or relative risk (RR) ratios and 95% confidence intervals (CI) . If these were not reported they were calculated where possible from data provided. Although we planned to pool data for a meta-analysis, it was not possible because included studies were either not sufficiently homogenous, or did not report enough data to calculate effect sizes. Authors of the included studies were contacted with a request to provide raw data but no further information was obtained.

Data interpretation was undertaken based on the classification described in Herbert et al, 2005. An odds ratio (OR) or relative risk (RR) demonstrates the likelihood of an injury occurring. An OR or RR less than 1 demonstrates that an injury is as likely to occur in people without the characteristic of interest, and an OR or RR greater than 1 demonstrates that the injury is likely to occur in people with the feature of interest (excessive/limited ROM and greater/lesser strength).[135] The 95% Confidence Interval (CI) was used to estimate the precision of the RR/OR. A narrow CI indicates a high precision while a large CI indicates a low level of precision. CIs that cross 1 indicate that the hip characteristic is not a strong predictor of increased risk.[136]

RESULTS

A total of seven prospective studies met the inclusion criteria and were retrieved for data extraction from the initial search of 41,420 titles (Figure 2). Five studies from the original search met the inclusion criteria and two more studies were retrieved through hand searching of bibliographies.

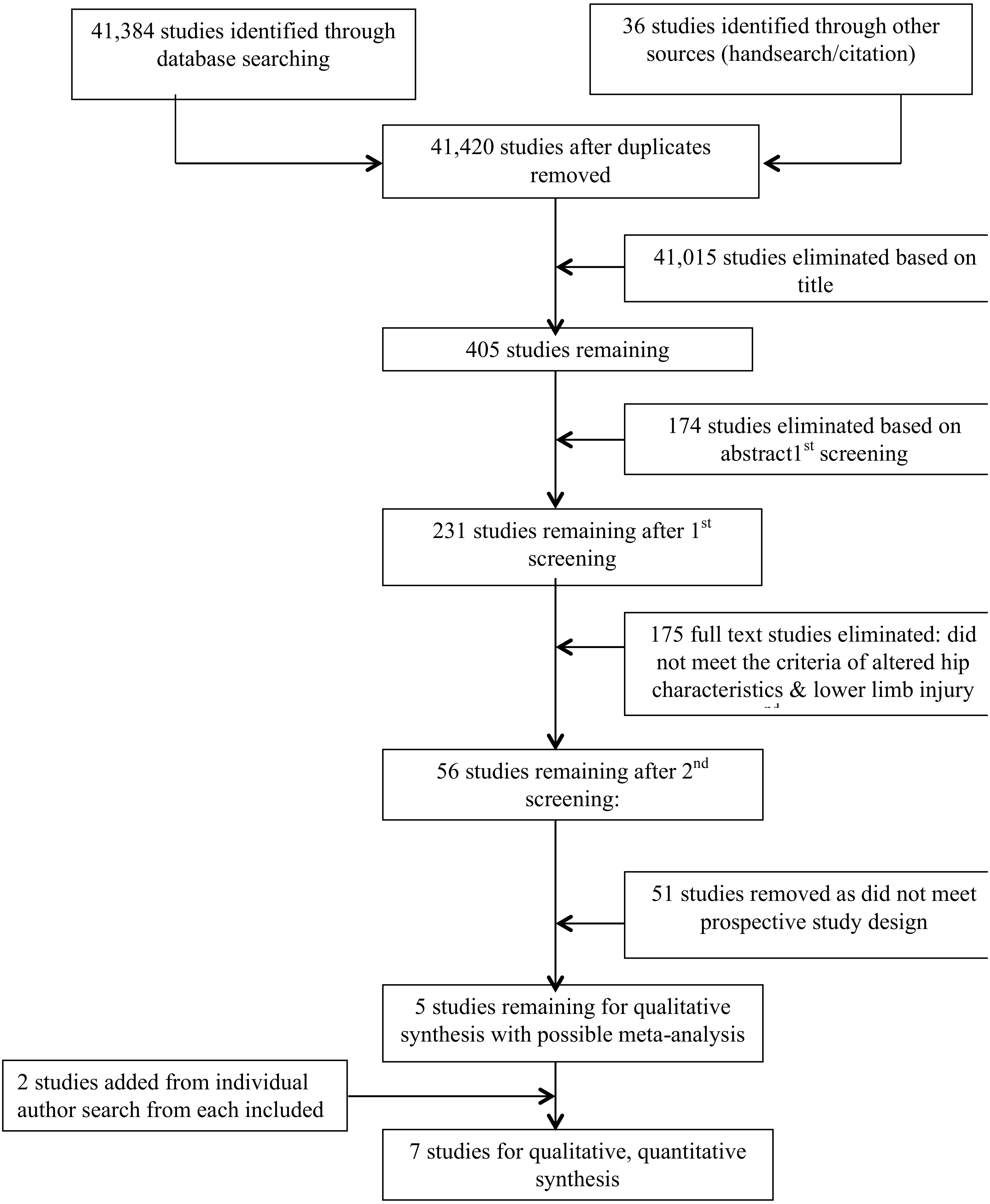


Figure 2 Flow chart of included studies

The hip characteristics reported in the included studies were hip range of motion and strength, quantified by non-functional or functional measures or both (Table 2). The term non-functional measures in this review refer to a static measure while functional measures refer to measurements that require movement (e.g. walking, jumping) and are performed actively by participants.

The injuries considered were lower limb stress fractures,[128-130] medial tibial stress syndrome (MTSS),[130] anterior cruciate ligament (ACL) injuries[133] and patellofemoral pain (PFP).[131, 132, 134] The sample size of the included studies ranged from 77 to 1319 with time to follow-up ranging between 10 weeks and 5 years. The participants were predominantly male (68%), relatively young (18-41 years) and active (Table 1). No prospective studies considered the relationship between femoral torsion and lower limb injury despite strong associations having been demonstrated in retrospective studies.

Table 2: Summary of included studies

Study	Participants	Follow up	Hip Measure	Lower Limb Injury	Odds Ratio/Relative Risk	Other Results
Giladi et al [128]	n=295 Infantry recruits All ♂ 18-20 yrs	14 weeks	Hip ER ROM(˚) Hip IR ROM(˚) Measured according to AAOS guidelines	91/295 stress # 55% tibia 34% femoral 9% other sites	ER ROM All type # RR 1.8 Tibia RR 2.0 Femoral RR 2.4 CI not able to calculate from the study	ER ROM Inj. >65°, Non-inj. <65° Tibial stress #, p = 0.037 Femoral stress #, p <0.01 All stress #; p = 0.023 IR ROM NS
Giladi et al [129]	n=289 Military recruits All ♂ 18-20 yrs	14 weeks	Hip ER ROM(˚) Hip IR ROM (°) Measured according to AAOS guidelines	91/289 stress # 52% tibial 30% femoral 9% in the tibial plateau 9% other sites	Not able to calculate from study	ER ROM mean(SD) Inj 58.5° (8.7), Non-inj 55.9 ° (8.7), p = 0.04 Tibial # Inj 58.8° (8.8), Non-inj 56.2° (9.0), p = 0.04 Femoral NS IR ROM NS
Yagi et al [130]	N=230 High school runners 134♂ 96♀	3 years	Hip ER ROM (°) Hip IR ROM (°) Measured in sitting with hip and knees flexed at 90° Isometric hip abductors test using 'break' method, position not given	102/230 MTSS Right 29; 20♂, 9♀ Left 23; 15♂, 8♀ Both 50; 25♂, 25♀ 21/230 Stress # Right 11; 2♀, 9♀ Left 6; 2♀, 4♀ Both 4; 3♀, 1♀	IR ROM Adjusted OR = 0.91, 95% CI 0.85-0.99	MTSS: Limited hip IR ROM is associated in female high school runners Inj 31.1 ± 9.9 °, Non-inj 25.5 ± 9.5 °, p<0.05 ER ROM NS Stress #: ER & IR ROM NS Abductor strength NS for MTSS and stress #

Study	Participants	Follow up	Hip Measure	Lower Limb Injury	Odds Ratio/Relative Risk	Other Results
Finnoff et al [131]	n=98 Runners 53♂/ 45♀ 14-18 yrs	2 years	Normalised isometric strength (break test, HHD) Abductors, Adductors (hip neutral, knee ext) Internal, External rotators (hip and knee 90˚) Flexors, Extensors	6/98 PFP	Hip abductor OR=5.35, 95% CI 1.46-19.53	Greater hip abductors strength significantly increases the risk of injury p <0.01
					Ab/add ratio OR = 14.14, 95% CI 0.90-221.06	Greater abduction:adduction strength ratios significantly increase the risk of injury p= 0.05
			Normalised isometric agonist-antagonist strength ratios; Abductors-adductors Flexors-extensors Internal-External rotators		Ext/Int rot ratio OR 0.01, 95% CI ≤ 0.01-0.44	Greater hip external:internal rotation strength ratio significantly decreased the risk of injury p = 0.02
Boling et al [132]	n= 1597 Naval Recruits 632♀/ 965♂ Age not stated	6 months to 2.5 years	Normalised isometric hip strength using make test and HHD Abductors (hip neutral, knee ext) Extensors (hip neutral, knee 90˚) Internal, External rotators (hip neutral, knee 90˚)	40/ 1319 PFP; 24♀, 16♂	Ext rot Adjusted RR = 4.02, 95% CI 1.03-15.72 In model looking at muscle strength and posture	Greater hip external rotator strength was a risk factor for developing patellofemoral pain 0.16 (%BW) at 10th percentile 0.28 (%BW) at 90th percentile p = 0.04

Study	Participants	Follow up	Hip Measure	Lower Limb Injury	Odds Ratio/Relative Risk	Other Results
Boling et al [132] (cont)			Hip kinematics during jump-land task measured using 3D motion analysis Flexion angle Adduction angle Internal rotation angle		Hip int rot Adjusted RR = 1.38, 95% CI 0.59-3.23 In model looking at 3D variables and posture	Increased hip internal rotation angle during jump-land task was a risk factor for developing patellofemoral pain -3.15 (%BW) at 10th percentile 18.19 (%BW) at 90th percentile p = 0.04
Thjis et al [134]	n= 77 Novice runners All ♀ 29-47 yrs	10 weeks	Normalised isometric hip strength using make test and HHD Flexors Extensors Abductors, Adductors Internal, External rotator Normalised isometric against-antagonist ratios Flexion/extension Abd/adduction Ext /Int rotation	16/77 PFP		NS
Liederbach et al [133]	n=298 Dancers ♂ and ♀ 18-41 yrs	5 years	Hip ER ROM (˚) Hip IR ROM (˚) Total leg strength calculated from combining isometric break-tests with HHD of flexors, abductors and adductors (kg)	12/298 ACL Injury		NS

ROM = range of motion, AAOS = American Academy of Orthopaedic Surgeon, ER= external rotation , IR = internal rotation,, NS = non-significant, OR= odds ratio, RR = relative risk, 95% CI= 95% confidence interval, ACL = anterior cruciate ligament, PFP = patellofemoral pain, MTSS = Medial tibial stress syndrome, # = Fracture, HHD = Hand held dynamometer, N = Newton,

Methodological quality

Although all included studies were of high quality and scored 14 or 15 (total score of 16 Table 1) they were not designed as prognostic/epidemiological studies and data were difficult to extract as the purpose of this review was not aligned with the purpose of the papers.

Non-functional measures

Four of the included studies measured hip range of motion,[128-130, 133] two were based on the American Academy of Orthopaedic Surgeon (AAOS) guidelines,[128, 129] one measured hip range of motion in sitting with the hip and knees flexed at 90°[130] and one measured passive hip joint range of motion.[133] Outcome measures for strength were derived from isokinetic and isometric hand-held dynamometry in five of the included studies[130-134] which included isometric individual muscle strength,[130, 133] total strength of the test leg (a combined measure of flexion, abduction and adduction),[133] normalised peak force of individual muscle groups,[131, 132, 134] and agonist-antagonist ratios.[131, 134]

Range of motion was reported in four studies.[128-130, 133] Three of these studies investigated range of motion as a causative factor for lower limb stress fracture,[128-130] one for MTSS[130] and one for ACL injury.[133] Greater range of hip external rotation was found to increase the risk for all types of lower limb stress fracture (RR = 1.8), tibial stress fracture (RR = 2.0) and femoral stress fracture (RR = 2.4).[128] Recruits suffering lower limb stress fracture demonstrated hip external rotation range greater than 65°[128] and 58° cut off points formed as a result of regression.[129] Limited internal rotation range was found to be a risk factor for MTSS in female high school runners

(OR = 0.91, 95% CI 0.85-0.99).[130] No difference in passive range of hip internal and external range of motion was reported between dancers with and without ACL injury.[34]

Strength of the hip musculature was investigated in five studies, three using normalised isometric muscle tests,[131, 132, 134] one using isometric muscle strength[130] and one using isometric muscle strength and combined strength measures.[133] Three studies investigated the relationship between hip strength and PFP,[131, 132, 134] one with MTSS and stress fracture[130] and one with ACL injury.[133] Significant strength differences were found between participants with and without PFP, in populations of midshipmen[132] and runners.[131] On individual muscle tests, significantly greater hip external rotator strength was found in midshipmen who developed PFP (RR = 4.02, 95% CI 1.03-15.72)[132]. Runners suffering PFP were found to have stronger hip abductors (OR=5.35, 95% CI 1.46-19.53).[131] Hip abductor strength was not found to be a risk factor for MTSS and stress fracture in high school runners[130] and no differences in hip muscle strength were found between injured and non-injured participants in the remaining PFP study of female novice runners[134] and dancers with non-contact ACL injuries. [133]

When agonist to antagonist strength ratios were compared, greater abductor: adductor strength was found to increase the risk of developing PFP (OR = 14.14, 95% CI 0.90-221.06)[131]. The same study also found that greater hip external rotation: internal rotation strength reduces the risk of PFP (OR= 0.01, 95% CI <0.01-0.44).[131]

Functional measures

Only one of the seven included studies measured range of motion and strength dynamically to determine their influence on PFP.[132] Both hip kinematics and kinetics were measured using 3-D motion analysis on a functional task of drop landing from a 30-cm height (Table 2). Greater hip internal rotation angle during landing however was found to be not significant in increasing the risk of developing PFP in midshipmen (RR=1.38, 95% CI 0.59 to 3.23)

Discussion

This systematic review revealed that only greater range of hip external rotation and greater hip external rotator strength were found to have a role in increasing the risk to developing lower limb injury in five out of seven included studies. Lower limb stress fractures in military recruits were predicted by greater external rotation range[128, 129] while limited range of internal rotation was found to be a protective feature from developing MTSS in adolescent runners.[130] PFP in midshipmen was predicted by stronger hip external rotators[132] and greater hip abductor strength in runners.[131] The remaining two studies did not find any significant relationships: the first examining hip strength and PFP in runners,[134] the second examining hip range of motion and strength and ACL injury in dancers.[133] Although retrospective data have also shown that extremes of femoral torsion were highly associated with knee pain[104, 105] no prospective study was found investigating this factor.

Range of hip external rotation was found to be greater in military recruits who developed lower limb stress fractures, particularly of the tibia.[128, 129] Although the two studies appear very similar a meta-analysis was unable to be performed due to the lack of data provided. Both studies used the same method of measuring hip range of motion (AAOS guidelines) in similar participant groups, but reported a different mean external rotation range for risk as greater than 65°of external hip rotation[128] and 58°.[129] The difference in the hip external rotation values might be due to the force used to produce external rotation of the hip, or whether the pelvis was stabilised during testing. Giladi et al, 1987[128] hypothesised that the greater hip external rotation may be a result of femoral retrotorsion, however no torsion measures were undertaken. These results may not be applicable to other populations as military recruits are required to perform high repetitions of loading type activities, compared to other populations.

Only one study considered hip motion during a functional activity, reporting a greater range of hip internal rotation during landing increased the risk of developing PFP.[132] However the confidence interval crossed 1 which suggests this is not a significant risk. This contrasts with other cross-sectional studies which reported that excessive internal rotation on landing has been associated with hip adduction and knee valgus.[137-142] Excessive knee valgus increases the Q-angle displacing the patella laterally relative to the tibial tubercle[143 144] which increases lateral compressive patellofemoral joint stress[145, 146] therefore predisposing to the development of PFP.

Strength in a range of movement planes is another hip characteristic that was found to predict PFP in two[131, 132] of the three included studies.[131, 132, 134] Generally these findings support retrospective studies of hip muscle strength being associated with

PFP[107, 108, 123, 124] however, data published by Boling et al appears to be in direct contrast with the current wisdom that weakness of hip external rotators is associated with increased risk of developing PFP.[123, 143, 144, 147] This contradiction in findings may be due to the sample population. The study by Boling et al examined naval recruits who perform high impact movements like jumping and landing so external rotators were deemed to be strongly recruited to counteract the increased internal rotation range (which was also found to be a risk for PFP) on landing. Future study needs to be undertaken to test this hypothesis. The contrasting finding may also be due to the different hip strength testing protocols. Boling tested hip external rotator strength in prone with the knee in 90° flexion and the hip in neutral while the other two studies tested the external rotators strength in sitting with the knee and hip in 90˚ of flexion. Some of the hip muscles are biaxial muscles (semitendinosus, semimembranosus, sartorius and tensor fascia lata) and also perform movement at the knee. It is plausible that these biaxial muscles are already in shorten position and firing when hip rotators were tested in prone with the hip in neutral. Therefore, it is plausible that the strength produced by the rotator muscle group may have been an accumulation of strength produced by other than rotators muscle group. In addition the CI reported for Boling's study was large (1.03-15.72) suggesting a low precision result.

Finnoff et al[131] reported that stronger hip abductors increased the risk of PFP. Hip abductor strength was tested in side-lying in Finnoff's study. Although historically the side-lying position for testing abductors and adductors strength has been preferred[148], clinically the supine position have been shown to offer an advantage in the assessment of isometric hip abductor and adductor strength using hand held dynamometry because it produces a smaller measurement variation, making it capable to detect small yet potentially clinically meaningful changes at the individual muscle level.[149] The CI reported for this feature was also large (1.46-19.53) again suggesting a low precision result.

The third study by Thjis et al[134] did not find any difference in hip strength measured between participants with and without PFP. This discrepancy may be due to the relatively short time follow-up of 10 weeks compared to the other two studies which had follow ups of greater than six months.[131, 132] As PFP is primarily regarded as a chronic condition, a 10 week follow up may not have been sufficient to examine the relationship between PFP and hip strength. Given the typically chronic nature of the condition symptoms may take longer than 10 weeks to appear after the commencement of an aggravating activity.

In the one study which considered the risk of ACL injuries in dancers, neither hip range of motion nor strength were found to be risk factors.[133] However, the sample group used may have also influenced the findings as dancers have a low incidence of ACL injury compared to other sports.[150] In soccer, a sport commonly associated with ACL injury, the mechanism of ACL injury is during side cutting movements and sudden changes of direction.[151] While these movements are common in dance they are not unanticipated which allows the dancer to preselect a well aligned movement pattern.[152] Therefore using dancers as a population for investigating the relationship between hip characteristics and injury may be more productive if investigating more commonly occurring dance injuries (e.g. ankle and foot injuries).[153, 154]

Conclusion

Of the seven studies which met the inclusion criteria for this review only five studies found that hip features, greater range of hip external rotation and greater hip external and abductor strength were factors in developing distal lower limb injury. Although greater hip external rotation range increased the risk of distal lower limb stress fractures in military recruits we cannot conclude how strong the relationship is because we were unable to calculate confidence intervals. Decreased hip internal rotation range is protective of MTSS in adolescent runners but the size of the effect is unknown. Greater hip external rotator and abductor strength appeared to increase the risk of PFP but the precision of this finding is low. Varying sample populations, measurement methods and follow-up periods may also contribute to the diversity of findings across the seven included studies. Well-designed, longitudinal studies utilising standardised measurement protocols with follow-up longer than six months and are warranted to clarify the relationship between hip strength, range of motion, femoral torsion and performance of functional tasks in predicting lower limb injury.

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Faculty of Health Sciences

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As co-authors of the paper "Development of a novel method for measuring femoral torsion using real time ultrasound. - A reliability study " we have confirmed that Eliza Hafiz made the following contributions:

- concept and design of the research proposal
- data collection
- analysis and interpretation of the findings
- drafting and revising the paper and critical appraisal of content

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CHAPTER 3

Development of a method for measuring femoral torsion using real-time ultrasound

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Development of a method for measuring femoral torsion using real-time ultrasound

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Abstract

Excessive femoral torsion has been associated with various musculoskeletal and neurological problems. To explore this relationship, it is essential to be able to measure femoral torsion in the clinic accurately. Computerized tomography (CT) and magnetic resonance imaging (MRI) are thought to provide the most accurate measurements but CT involves significant radiation exposure and MRI is expensive. The aim of this study was to design a method for measuring femoral torsion in the clinic, and to determine the reliability of this method. Details of design process, including construction of a jig, the protocol developed and the reliability of the method are presented. The protocol developed used ultrasound to image a ridge on the greater trochanter, and a customized jig placed on the femoral condyles as reference points. An inclinometer attached to the customized jig allowed quantification of the degree of femoral torsion. Measurements taken with this protocol had excellent intra- and inter-rater reliability ($ICC_{2,1} = 0.98$ and 0.97, respectively). This method of measuring femoral torsion also permitted measurement of femoral torsion with a high degree of accuracy. This method is applicable to the research setting and, with minor adjustments, will be applicable to the clinical setting.

Keywords: femoral torsion, ultrasound, reliability, greater trochanter

(Some figures may appear in colour only in the online journal)

Introduction

Femoral torsion or femoral anteversion is an interchangeable term use to indicate twisting of the femur resulting in the femoral neck and the femoral condyles sitting in a different angle on a transverse plane. Variations in femoral torsion, particularly excessive femoral anteversion, are thought to increase the risk of musculoskeletal injury to the hip joint and adjacent structures (Kitaoka *et al* 1989, Reikeras and Hoiseth 1982, Eckhoff *et al* 1994a, 1994b). Exploration of this relationship requires an accurate and reliable method of measuring femoral torsion. Bone remodels in response to the mechanical stresses imposed through load bearing and muscle force, therefore the angle of femoral torsion varies between individuals, depending on the stresses imposed (Alvik 1962). Femoral torsion, as characteristically found in healthy adults (Cibulka 2004, Kay *et al* 2000) refers to the distal femoral condyles being medially rotated 10–20° in the transverse plane relative to the axis of the neck of femur (figure 1). Medial rotation of the condyles of more than 20° is considered to be excessive femoral anteversion, and less than 10°, i.e. relative lateral rotation, is considered to be femoral retroversion (Tonnis and Heinecke 1999).

Both excessive femoral anteversion and retroversion are thought to impose a bias towards hip internal or external rotation respectively, with the potential for overload and injury at the hip joint, or at some point lower in the kinetic chain (Staheli *et al* 1980, Pitkow 1975, Kling and Hensinger 1983, Tonnis and Heinecke 1991, Swanson *et al* 1963, Nyland *et al* 2004, Eckhoff *et al* 1994a, 1994b). For example, an individual with excessive femoral anteversion may have a total range of hip rotation within normal limits, i.e. approximately 90° (Magee 2002), but present with 70° of internal rotation and 20° of external rotation instead of similar internal and external rotation ranges. This discrepancy will be reflected in a change in the midpoint of rotation range. This phenomenon has been described at the humerus (Whiteley *et al* 2006), and when the analogous situation occurs at the hip, may result in altered stresses on the capsuloligamentous and labral structures. In light of the potential sequelae of abnormal femoral morphology, there is an increasing awareness of the importance of assessing femoral version, and the need for a reliable clinical measure.

Radiological measures, including plain radiography, computerized tomography (CT), and magnetic resonance imaging (MRI), are generally used to determine femoral torsion. Although both radiography (Phillips *et al* 1985) and CT (Hernandez *et al* 1981, Botser *et al* 2012, Delialioglu *et al* 2006) have been shown to be reliable tools, they both carry the risk of exposure to ionizing radiation, and are therefore not recommended for repeated measurement (Peterson *et al* 1981, Sullivan *et al* 1982). In the last ten years there has been a shift towards the use of MRI, which avoids the hazards of ionizing radiation and also enables imaging in a variety of planes (Guenther *et al* 1995, Kulig *et al* 2010). Enabling accurate visualization of non-ossified cartilage in joints as well as growth plates, MRI provides precise and safe estimation of the axis of the neck of femur (Guenther *et al* 1995). This method, however, requires costly resources (Tamari *et al* 2005) and is not readily available in all communities.

Ultrasound has been used to measure torsion in dried femora as well as *in vivo* (Zarate *et al* 1983, Baratelli *et al* 1985, Terjesen and Anda 1990, Terjesen *et al* 1993, Kulig *et al* 2010). However, evidence concerning its accuracy is conflicting. Early quantification of femoral torsion using ultrasound was based on the method described by Moulton and Upadhyay (1982) using superimposed images of the proximal and distal bony landmarks of the femur. When compared with CT and MRI, this method overestimated femoral torsion (Baratelli *et al* 1985).

When imaging facilities are not available, health professionals rely on clinical assessments for measuring femoral torsion, generally using the greater trochanter as a reference point

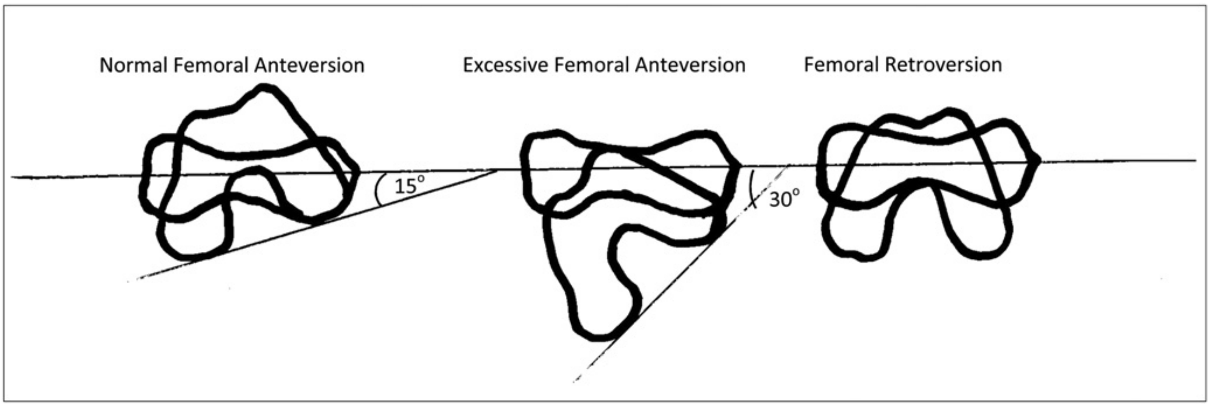

Figure 1. Femoral torsion.

(Ruwe *et al* 1992, Netter 1940). Ruwe *et al* (1992) measured femoral torsion, using a clinical assessment, in 91 children with a variety of congenital deformities. Measurements were taken in prone with the knee in 90° flexion. The femur was passively rotated via the distal tibia until the greater trochanter was felt to be at its most prominent position laterally. The angle between the vertical and the axis of the tibia was measured. This clinical assessment of femoral torsion in a young population was found to have high correlation with femoral torsion measured intraoperatively ($r = 0.930$ right hip; $r = 0.877$ left hip). However, palpation of the greater trochanter in adults has been shown to have poor inter- and intra-rater reliability (Moriguchi *et al* 2009). The greater trochanter in adults is commonly 2–4 cm^2 in area and lies deep to the skin, subcutaneous fat and the gluteal fascia. Therefore palpation may not be as easy and reliable as in children, potentially introducing error into the measurement. Femoral torsion measurements performed clinically compared to MRI on participants with higher BMI had larger measurement errors maybe due to the soft tissue overlying the greater trochanter (Souza and Powers 2009).

Only the lateral surface of the greater trochanter can be palpated in the living due to the complexities of the bony surface, muscle attachments, location of bursae, and the variable thickness of the layer of subcutaneous fat (Grey 1980). Therefore visualization under real-time ultrasound was hypothesized to enable more reliable location of a landmark on the greater trochanter. Furthermore, ultrasound is non-invasive, relatively inexpensive and has widespread availability in medical and physiotherapy clinics. In addition, the validity of ultrasound measurement of humeral torsion has been established using the gold-standard of CT scans (Myers *et al* 2012). The aims of this study were firstly, to develop and describe a new clinical method for measuring femoral torsion between the greater trochanter and the condyles using ultrasound and a customized condylar jig, and secondly, to determine its reliability.

Methods

While the definition of femoral torsion varies among anatomists, anthropologists and clinicians, the head, neck and condyles of the femur are typically used to define and measure torsion. Therefore most imaging protocols incorporate all three elements. However, the actual site of femoral torsion remains unknown as femoral torsion appears to change during skeletal maturation before becoming relatively stable. It is theorized that torsion occurs at the physes. We measured femoral torsion between the physes connecting the femoral shaft to the greater trochanter.

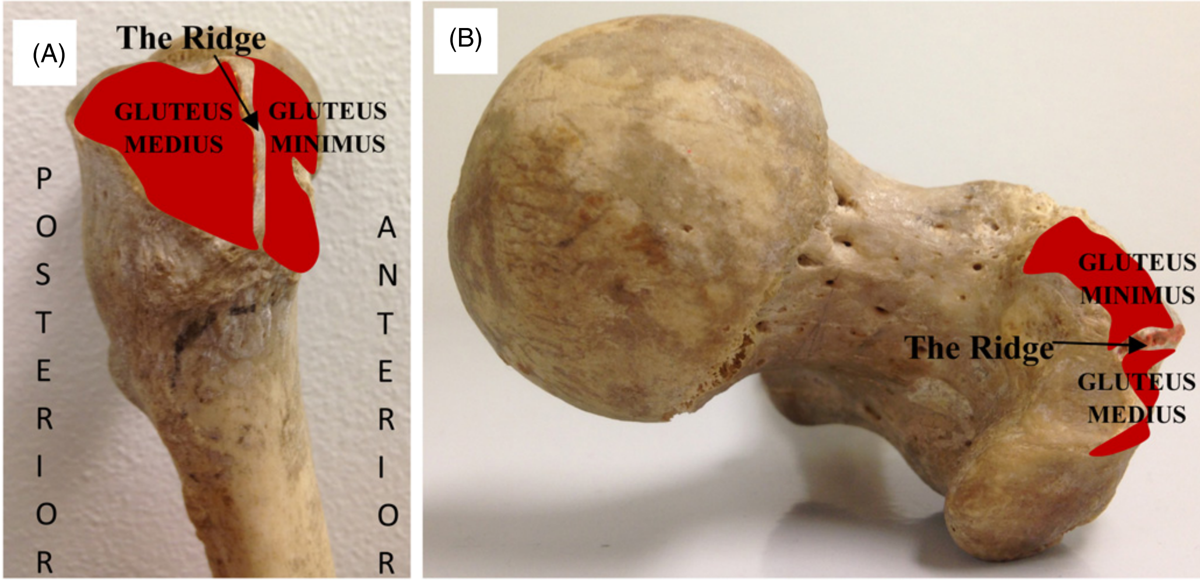

Figure 2. Dry bone specimen demonstrating (A) lateral view and (B) superior view of the ridge between the facets providing insertion sites for gluteus medius and gluteus minimus muscles.

As we were measuring the magnitude of femoral torsion, the proximal and distal landmarks needed to be identified and established. The landmark used to standardize the location of the proximal femur was the ridge of the greater trochanter, and was located using real-time ultrasound. However, in order to establish a reliable reference line at the distal condyles, a customized jig was developed. Therefore, the development of the measurement is presented in three sections; (i) identification of landmarks, (ii) development of the condylar jig and (iii) the measurement protocol.

Identification of landmarks

To identify a consistent landmark on the greater trochanter, 30 dry adult human femora were evaluated. A consistent ridge on the greater trochanter was visually identified on all 30 specimens. Anatomically, this ridge is the border between the anterior and the lateral facets (Pfirrmann *et al* 2001) which constitute the tendon attachments of vastus lateralis anteromedially, gluteus minimus anterolaterally, and gluteus medius posterolaterally (figure 2) (Grey 1980).

To confirm the ability to visualize the ridge using ultrasound, a bag filled with water was used as a conducting medium between the transducer and the cadaveric femora ($N = 30$). The ridge was visualized as a peak on the ultrasound image although the peak appearance differed among femora. Most femora had only one prominent peak along the ridge, however, 20% had two prominent peaks. Where two peaks were identified, the most cephalad peak was chosen as the landmark for the measurement.

Identification of landmarks for the condylar axis of the distal femur was also required for accurate assessment of femoral torsion (Davids *et al* 2002). This axis runs through the medial and lateral femoral condyles which are superficial and relatively easy to localize and palpate in most individuals. However, for the purpose of this study, real-time ultrasound imaging was used to identify the most superficial aspect of each condyle to standardize the condylar jig placement.

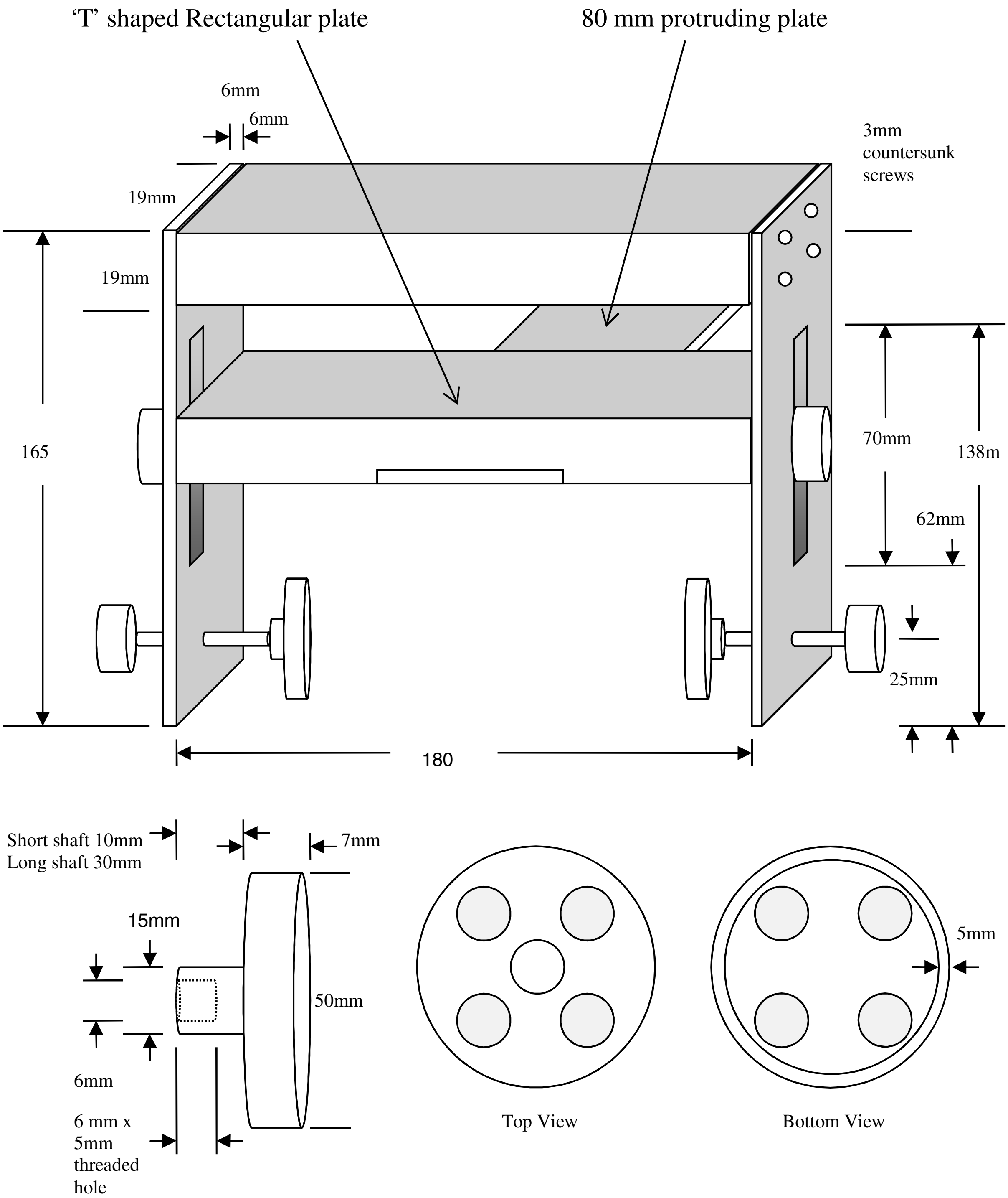

Figure 3. Prototype image of the torsion jig.

The condylar jig

A condylar jig was custom designed to provide a reference axis for the distal femur.

Figure 3 shows the prototype drawing of the jig. The main frame of the jig was designed as an inverted 'U' shape to fit the knee, and it housed a digital inclinometer. The dimension of the main frame is 165 mm $\times$ 190 mm. The jig was fashioned from aluminium to ensure it was lightweight and would allow positioning of the femur during the measurement process. After ultrasound-assisted location of the distal condyles, the jig was secured to the condyles by moulded plastic cups inserted at the metal base of the inverted 'U' shape. After testing

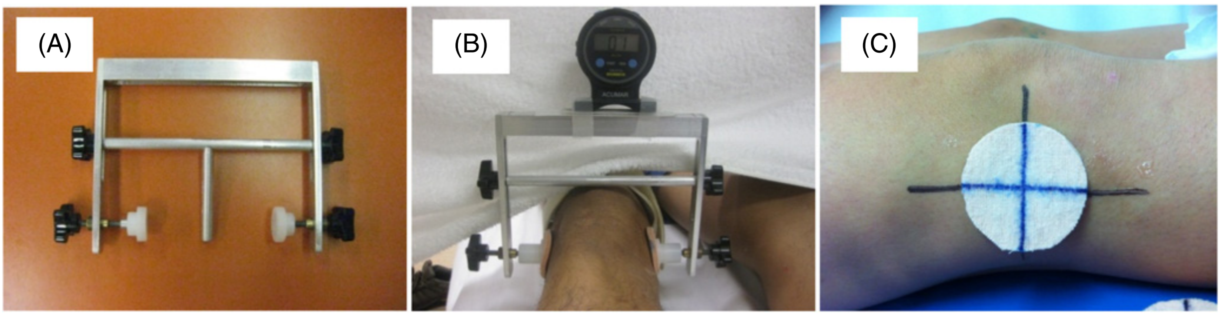

Figure 4. Setup for measuring femoral torsion, including (A) the condylar jig, (B) prototype *in situ* with inclinometer attached, (C) the padding with the cross on the lateral condyle.

the prototype, the cup diameters were reduced to 30 mm to ensure a more comfortable fit on the condyles. The shaft attaching the cups came in three different lengths to fit participants' varying physical morphologies. Padding was placed between the skin and the cups to minimize discomfort as the condylar jig was tightened.

The initial design of the jig included a movable 'T' shaped bar that was fastened to the top of the participant's thigh to stabilize the thigh and absorb a portion of the weight of the jig. The rectangular bar was changed to a rod to allow for smoother movement and to fit the contour of the soft tissues to minimize participant discomfort (figure 4(A)). The 80 mm long protruding rectangular plate positioned in the centre of the 'T' was also substituted with a rod which prevented tilting of the jig. A hole was drilled through the middle of the protruding rod to secure a velcro strap which was secured on the thigh to minimize any unnecessary soft tissue movement. A digital inclinometer, with 0.1° increments, was attached to the top of 'U' of the metal frame to measure the femoral torsion angle.

Measurement protocol

Using the landmark on the greater trochanter, and the condylar jig marking the distal condylar axis, femoral torsion could be measured. *In vivo*, the trochanteric ridge was identified using a Siemens ACUSON X300 diagnostic real-time ultrasound unit and a linear array transducer with a variable frequency of 3–8 MHz. The 3–8 MHz transducer was used to ensure high resolution while still penetrating sufficiently deeply to image the trochanter. Distally, although the condyles are relatively easy to palpate, a second linear array transducer with a higher frequency of 5–13 MHz was used to confirm the most superficial point of the condyles. This transducer was used as the higher frequency gives better resolution for this more superficial structure than the lower frequency transducer. The rotational position of the condyles was quantified using the Acumar™ digital inclinometer attached to the condylar jig (figure 4(B)). Both the ultrasound transducer and the inclinometer were calibrated before each measurement.

Two people were required for the measurement protocol: one operated the real-time ultrasound (the operator) to locate the trochanteric ridge and the epicondyles, and an assistant who moved the lower limb to achieve internal or external rotation of the femur, guided by the operator who aimed to optimize the image. Participants were positioned in supine lying, with the hip and knee relaxed. The first step was to identify the femoral epicondyles using palpation, confirmed by real-time ultrasound. The transducer was placed longitudinally on the lateral surface of the proximal tibia and moved cephalad until the tibiofemoral joint line was visualized. The transducer was then rotated 90° into vertical alignment and moved further cephalad until the lateral epicondyle appeared on the screen. When located, a cross was drawn

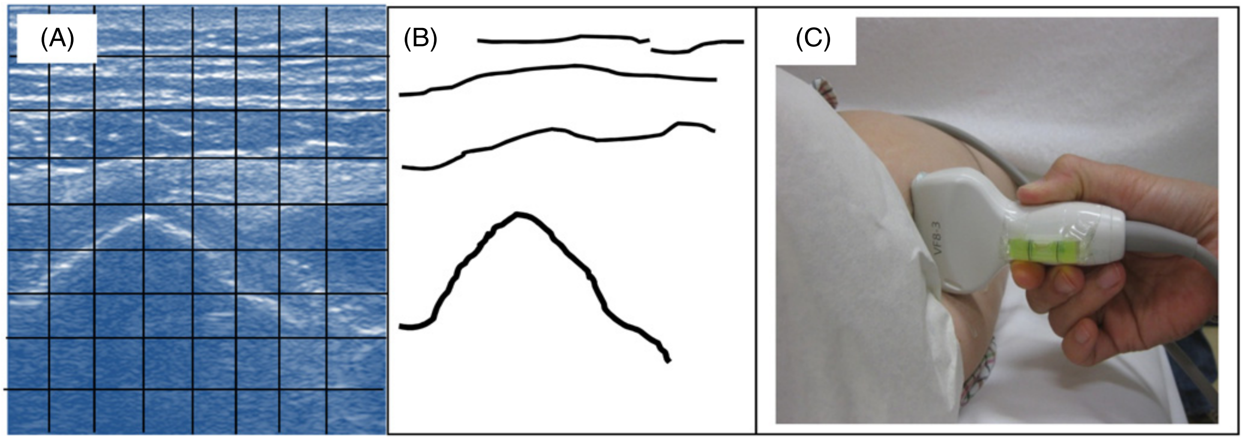

Figure 5. (A) Visualization of the trochanteric ridge. Ultrasound image *in vivo* with the grid on the screen and (B) schematic. (C) The spirit level attached to the transducer while insonating the greater trochanter.

on the epicondyle to allow accurate placement of the condylar jig. This technique was repeated to locate the medial epicondyle. The moulded cup paddings were also marked with a cross to indicate the cup centre, and aligned with the cross marked on the epicondyles (figure 4(C)). The jig was fastened securely to the condyles to minimize soft tissue movement that might cause measurement error. An Acumar™ digital inclinometer was calibrated to the horizontal, then attached to the condylar jig and positioned so that the display faced the assistant.

The next step was to identify the ridge of the greater trochanter and standardize the position of the proximal femur. With the hip in neutral rotation, the operator palpated the greater trochanter of the femur, positioned the 3–8 MHz linear array ultrasound transducer vertically at the mid shaft of the femur and moved it in a cephalad direction towards the greater trochanter. When the 'peak' image appeared on the screen (figures 5(A) and (B)), the operator continued the cephalad movement until the ridge disappeared and then moved the transducer in a caudal direction until the peak image returned to the screen. A spirit level attached to the transducer head was used to ensure standardization of the transducer orientation throughout the measurement procedure (figure 4(C)).

The assistant then passively rotated the leg as instructed by the sonographer until the peak of the ridge was most superficial on the screen, reflecting the most lateral position. A grid placed on the ultrasound screen assisted the sonographer to find the most superficial point (figure 4(A)). In this position, it was assumed that the head-neck-greater trochanter axis lay in the frontal plane of the body. The assistant recorded the reading from the inclinometer as the angle of femoral torsion.

Reliability

Intra- and inter-rater reliability of the new protocol was assessed using three raters and 40 participants.

Raters

Three raters, all physiotherapists, participated in the study. Raters had between 5 to 20 years of clinical experience and no or minimal experience with real-time ultrasound. Real-time ultrasound training was provided by an experienced and accredited sonographer. Rater 1

Figure 6. Ultrasound assessment of femoral torsion using a drape to blind the operator to leg position.

performed the measurement on two occasions and Raters 2 or 3 performed the measurement on the second occasion only. The raters were blinded to each other’s results.

Participants

Forty healthy participants (12 males, 28 females) aged 22–58 years (mean $\pm$ SD; 22.9 $\pm$ 8.7) were recruited to the study. Participants were included if they had no previous trauma or surgery to the hip, and no hip or groin pain at the time of assessment. Only one randomly allocated hip was tested in each participant (19 right and 21 left hips). All participants were fully informed of the nature of the research and provided written consent. The study was approved by the University of Sydney’s Human Research Ethics Committee.

Procedure

To determine intra-rater reliability, Rater 1 performed the real-time ultrasound measurement on two different occasions one week apart. To determine inter-rater reliability, a second rater performed the real-time ultrasound measurements at the second test occasions. A drape was placed between the participant’s hip and knee to ensure Rater 1 was blinded to the final position of the leg, and the ultrasound screen was not visible to the assistant (figure 6). All skin markings on participants were removed between raters. To minimize bias, Rater 1 was not informed of the results of any measurement until all data collection from both occasions

Table 1. Intra-rater and inter-rater reliability.

Rater	*n*	ICC (95% CI)	SEM	Per cent close agreement
R1	40	0.986 (0.97–0.99)	0.5	1° (52%) 2.7° (80%)
R1:R2/R3	40	0.977 (0.96–0.99)	0.6	1° (55%) 2.7° (80%)

n, number of participants; R1, Rater 1; R2, Rater 2; R3, Rater 3; ICC, intraclass correlation coefficient; SEM, standard error of the measurement.

was complete. The measurement protocol was repeated three times on each occasion by each rater.

Statistical analysis

For all analyses, the average of the three femoral torsion measurements was used. The results were analysed using intraclass correlation coefficients ($ICC_{2,1}$) (Portney and Watkins 2009), Bland–Altman plots and per cent close agreement. The correlation data were interpreted using the criteria of Fleiss (1999) where ICC < 0.4 denotes poor correlation, >0.4–0.75 fair to good, and >0.75 excellent correlation. The standard error of measurement (SEM) was used to estimate the degree of difference between measurement occasions and provide information about how the measurements were distributed around the raters' true scores. Percentage agreement was used to measure inter-rater agreement. Bland–Altman plots were used to determine bias.

Results

The mean angle and (SD) of femoral torsion measured by Rater 1 on the first session was 8.0° (3.9) and 8.27° (3.2) on the second session. The mean angle of femoral torsion measured by Rater 2/3 was 7.7° (3.6). Both intra-rater reliability ($ICC_{2,1} = 0.98$; 95% CI 0.97 to 0.99), and inter-rater reliability ($ICC_{2,1} = 0.97$; 95% CI 0.95 to 0.98) were excellent (table 1). Fifty per cent of the measurements were within 1° both within and between raters and within 2.7° for 80% of the measurements (figures 7 and 8). The largest difference between raters was 9.3°. The Bland–Altman plot (figures 9 and 10) indicated that inter- and intra-rater reliability did not change systematically with increasing magnitude of torsion. Standard error of measurement was 0.5° and 0.6° respectively for intra-rater and inter-rater reliability measurements.

Discussion

We designed a method for measuring femoral torsion that is safe and inexpensive. Our measurement protocol presents several attractive features over other available methods. Firstly, the application of the condylar jig and the ultrasound is more reliable than other simple clinical methods. Secondly, the measure can be readily performed during a physical examination by a clinician following minimal instruction. Finally, patients are not subjected to ionizing radiation, which is particularly important for patients requiring repeat measures, such as for monitoring correction of rotational deformity post-surgery in children. Our method, using real-time ultrasound, was found to have excellent intra- and inter-rater reliability.

Our new method of measuring femoral torsion was designed in a research setting therefore a custom-made condylar jig was built to increase the validity, reliability and the reproducibility of the measurement. The construction of the jig is simple, made from lightweight aluminium and plastic cups which are easily available in local hardware stores. The jig provides a reliable 90

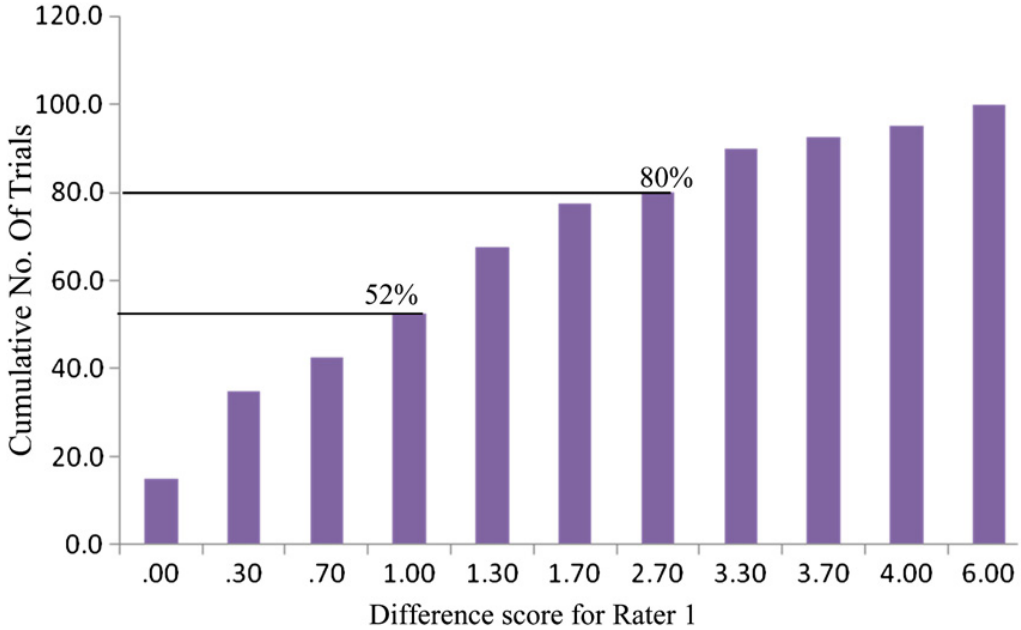

Figure 7. Per cent close agreement for Rater 1 on two measurement occasions.

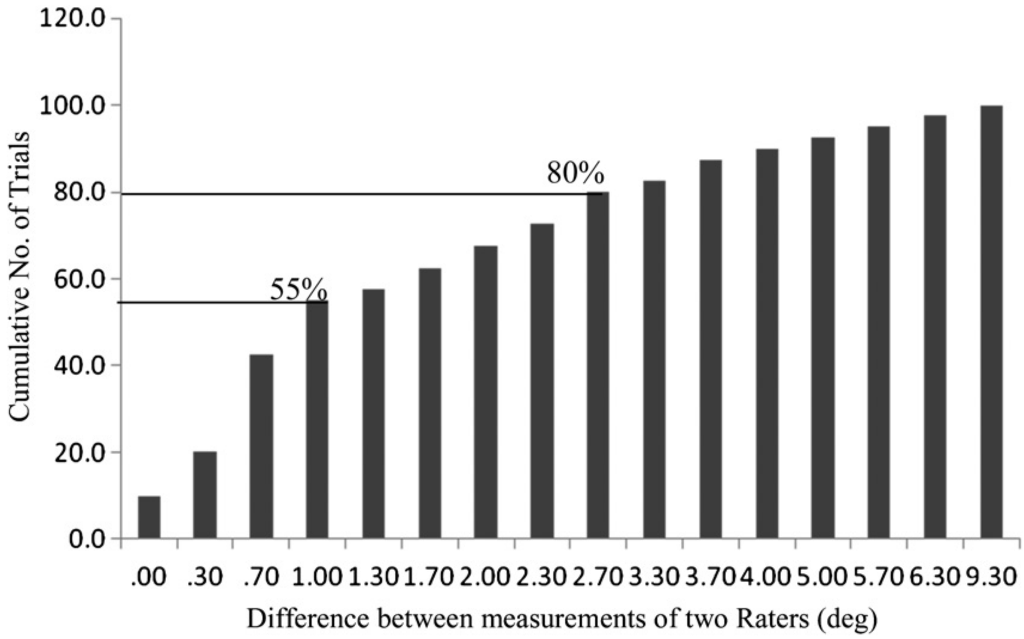

Figure 8. Per cent close agreement between two raters.

distal reference line and its tight fitting on the condyles minimizes movement error. Three additional mechanisms, the ‘T’ rod placed on top of the knee, the 80 mm protruding rod along the thigh and the velcro strap also ensured minimal soft tissue movement and a snug fit of the jig.

To our knowledge, this new method is the first to measure torsion using these particular landmarks, the ridge of the greater trochanter and the condylar axis. Previously, femoral torsion utilizing real-time ultrasound has been measured between the femoral neck and head, and the posterior condyles (Hudson *et al* 2006, Kulig *et al* 2010). We initially investigated this method and found several difficulties; accurate identification of the neck and head of the femur, accurate positioning of the posterior condyles in people with higher BMI, and inadequate stabilization of both the proximal and distal landmarks. Each of these issues could potentially 91

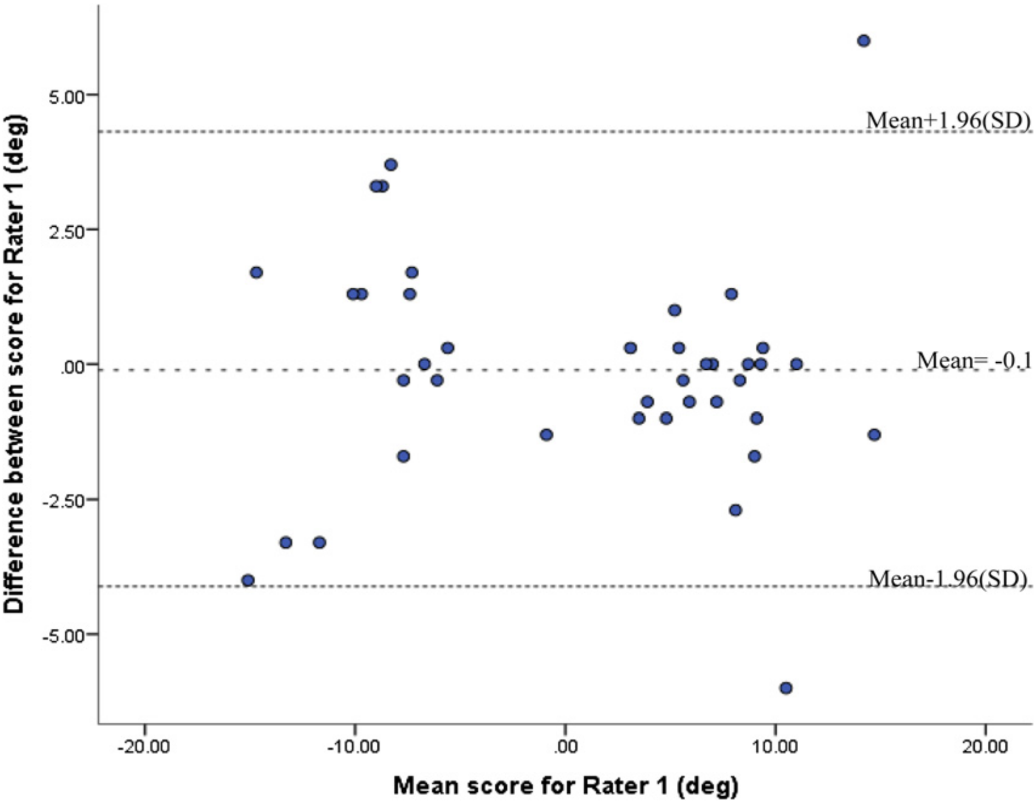

Figure 9. Bland–Altman plot comparing femoral torsion score measured by Rater 1. SD, standard deviation.

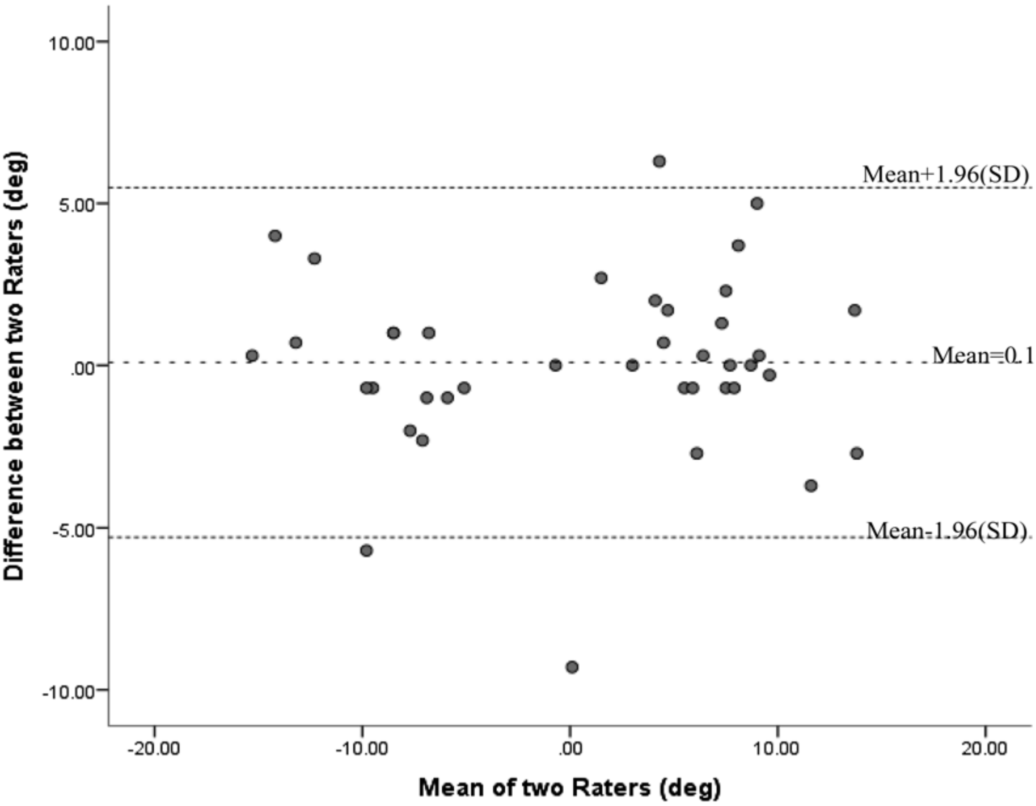

Figure 10. Bland–Altman plot comparing femoral torsion score measured by Rater 1 and Rater 2. SD, standard deviation.

contribute to the error of measurement. Our method improved identification of landmarks by using more superficial landmarks both on the proximal (the ridge of the greater trochanter) and distal (the medial and lateral condyles) femur. Accurate positioning was obtained by use of a spirit level attached to the ultrasound transducer which allowed consistent placement of the ridge of the greater trochanter in the horizontal plane. With the proximal femur placed in a consistent position, the inclinometer could measure the angle subtended by the distal condyles without the need for external stabilization.

While Kulig *et al*'s (2010) study only reported on intra-rater reliability, our method has high intra- and inter-rater reliability which supports its use in the clinical setting, across clinicians and sites. Intra-rater reliability was high using either method while the SEM was smaller using our protocol. The better SEM achieved in our study may be due to the greater accuracy in determining and standardizing the distal axis by the use of the condylar jig.

We did not determine the validity of this measurement technique. However, a similar study of humeral torsion using the same technique was found to be highly accurate ($R = 0.80$, $R2 = 0.64$, $p < 0.001$) when validated against CT images (Myers *et al* 2012). This finding suggests that ultrasound not only provides a reliable but also a valid alternative to CT scanning in obtaining bone rotational measures (in this case humeral torsion), therefore avoiding exposing patients to radiation. Our technique should also be validated in the future against a gold standard, such as MRI. This would also explore whether the ridge of the greater trochanter is altered in people with pathological or congenital abnormalities, which would influence the usefulness of this technique in these populations.

Although our method was conducted using two assessors, we subsequently trialled the method using one sonographer without an assistant, testing a small group of five participants and returning similar levels of reliability. The method is relatively quick to administer, taking about 10–15 min to examine both hips. The accuracy of this method was also enhanced by the use of a digital inclinometer with 0.1° increments, enabling highly accurate quantification of femoral torsion. This level of reliability plus quick administration supports its use in clinical and research settings in both normal and pathological populations.

In the clinic, our method can be used to measure femoral torsion along with other musculoskeletal assessment techniques. As femoral torsion has been found to be associated with development of osteoarthritis of the hip and the knee, and anterior knee pain (Eckhoff *et al* 1994b, 1994a), measuring femoral torsion in patients with lower limb pain or injury may provide better targeted, rehabilitation, and possibly enable design of strategies to prevent lower limb injury. This real-time ultrasound assisted method will also be useful to investigate associations between femoral torsion and lower limb pathology in the normal population, athletes, dancers, and populations with congenital deformities such as cerebral palsy.

Conclusions

We designed a simple, non-invasive, and relatively inexpensive method for measuring femoral torsion that can be used in the clinic. This method can be effectively performed by various health professionals, with minimal training in the use of real-time ultrasound. We found this method to have excellent reliability.

Acknowledgments

All authors have approved the manuscript and agreed with its submission to *Physiological Measurement* and therefore is formatted to the requirement of *Physiological Measurement*. We also confirm that there is no conflict of interest in carrying out this research and this research was not funded by any scheme or body.

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Faculty of Health Sciences

Publication Statement

As co-authors of the paper "The association between femoral shaft torsion and active hip proprioceptive acuity in healthy adults" we have confirmed that Eliza Hafiz made the following contributions:

- concept and design of the research proposal
- data collection
- analysis and interpretation of the findings
- drafting and revising the paper and critical appraisal of content

Elizabeth Jean Nightingale.......................... Date: 7-8-14

Claire Hiller .... Date: 6/8/14

Leslie Nicholson...................................... Date: 11/8/14

Kathryn Refshauge................................... Date: 7/8/14

CHAPTER 4

The association between femoral shaft torsion and active hip proprioceptive acuity in healthy adults.

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Abstract

Background: Bone morphology of the humerus has been proposed to influence lateral rotation proprioceptive acuity at the shoulder. A similar relationship however has not been examined at the femur.

Objective: To determine the relationship between the magnitude of femoral shaft torsion and active hip lateral rotation proprioceptive acuity.

Participants: Forty healthy adults; 23 females, 17 males with mean (SD) age 26.85(7.8) years.

Methods: Femoral shaft torsion was measured using real-time ultrasound. Hip lateral rotation proprioception was measured using active reproduction of three hip joint angles (10% off neutral, 50% or mid-range and 90% of maximum range of external rotation). The absolute angular error was recorded between the tester and participant position.

Results: Mean femoral shaft torsion was 10.8 ±5.6°. A negative weak to moderate association was found between extent of medial femoral shaft torsion and absolute angle error close to end of lateral hip rotation range ($r=-0.325$, $p=0.04$). A weak association was found between the extent of medial shaft torsion and absolute angle error at mid lateral rotation range. No association was found between extent of femoral shaft torsion and hip proprioceptive acuity close to the beginning of lateral rotation range.

Conclusion: Medial shaft torsion is correlated to the active hip proprioceptive acuity only at the angle closer to maximum range of lateral rotation.

Keywords: Femoral shaft torsion, femoral antetorsion, femoral retrotorsion, hip proprioception

Introduction

Propriception encompasses the sensation that arise from the discharge signals from ligament, joint and muscle receptors [87] The term proprioception encompasses both the sensation of joint movement (kinesthesia) and joint position. [155] Proprioception enables discrimination of movement of limb segments both individually and relative to one another .[156] Afferent information and neurological feedback mechanisms originating in articular and musculotendinous structures provide an important component for maintaining good proprioceptive acuity in healthy joints. [157-161] In large joints such as the hip, afferent information from muscle and tendon receptors is believed to provide the most useful proprioceptive information. [155] The joint capsule plays a less important proprioceptive role in large joints, however it provides useful information in signalling physiological end-points in range to prevent joint damage. [162]

Proprioception can only be measured indirectly. Kinaesthesia and joint position sense (JPS) are two of the submodalities that have been described in measuring proprioception. Although there are several methods to measure proprioception, there is lack of consensus as to which method is preferable and which modality is most appropriate to use .[163] Kinaesthesia is commonly assessed by measuring the threshold to detect passive movement while JPS is assessed by measuring the reproduction of either passive or active positions. [164-166]

There is limited research examining proprioception of the hip, with the majority of hip joint proprioceptive studies undertaken in the elderly after hip fracture or arthroplasty. [84,]

[167-169] Comparison of hip proprioception with matched individuals with asymptomatic hips has revealed no difference in proprioceptive acuity. [168] Hip joint position sense is shown to be unaffected by aging. [170]

Torsion (or twisting) is a structural variability found in long bones of the skeleton. In the femur, torsion is first identified at seven weeks of gestation [23] and progresses throughout skeletal growth. [26] Normal femoral torsion in healthy adults is conventionally defined when the distal femoral condyles are medially rotated 10-20 degrees in the transverse plane relative to the axis of the neck of femur. [12, 171] Medial rotation of the condyles of more than 20 degrees is termed excessive femoral antetorsion and results in an inward facing patella and an in-toeing posture and gait. Less than 10 degrees, i.e. relative lateral rotation, is termed femoral retrotorsion and when extreme results in an outward facing patella and an out-toeing posture and gait (Figure 1). [172] Despite these definitions, the actual site where torsion occurs, and the underlying causes and mechanisms of torsion development remain obscure. [28] Total femoral torsion is likely to be a composite measure of torsion between the femoral neck and the shaft, and torsion more distally along the femoral shaft.

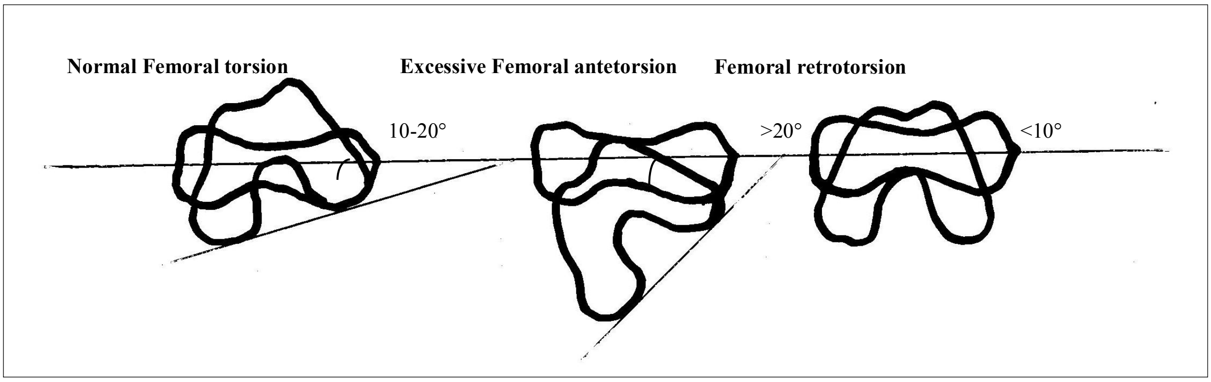

Figure 1 Schematic drawing of total femoral torsion of the right hip. This includes torsion achieved between the head/neck of the femur and the proximal shaft and that achieved between the proximal shaft (Greater trochanter) and the femoral condyles.
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The amount of femoral torsion is believed to affect the symmetry of hip rotation range. [41] In children, both excessive femoral antetorsion and retrotorsion have been found to result in an asymmetrical rotation range. An excessively antetorted femur has been associated with a greater range of medial rotation over lateral rotation. Likewise, a retrotorted femur has been associated with greater lateral rotation over medial rotation. [4, 26, 122]

Asymmetrical range of hip rotation may induce capsuloligamentous injury in addition to mechanical disruption of articular structures and shortening of associated muscles. [42] It is plausible that the less than optimal biomechanics of excessive femoral torsion (ante or retro) would affect the sensory input to and motor output from the hip and lower limb. Altered tension in passive soft-tissue restraints (joint capsules and ligaments) and altered length/tension relationships of active restraints (musculature) may affect afferent input from mechanoreceptors in these structures. This altered input may affect the proprioceptive acuity at joints of the lower limb.

In the upper limb, humeral torsion (measured in the shaft of the humerus) was found to be associated with better proprioceptive acuity of the shoulder joint in elite, adolescent baseball players. [78] In the lower limb, despite having similar structural variability in the femur (femoral torsion), the relationship between femoral torsion and hip proprioceptive acuity is yet to be determined. Therefore the aim of this study was to investigate the relationship between femoral shaft torsion and hip proprioceptive acuity in a healthy adult population.

Methods and Participants

Forty staff and students (23 females, mean age (SD) 26.9 (7.8) years) from the Faculty of Health Sciences at the University of Sydney volunteered to participate in this study. Exclusion criteria included; age over 55 years, previous hip/femur surgery, or the presence of congenital hip disorders. Approval for the study was obtained from the University of Sydney's Human Research Ethics Committee (2012/577).

Measurement Protocol

The protocol was the same for each participant and the same assessor undertook torsion and proprioceptive measurements of all participants. Femoral shaft torsion was measured first followed by the proprioception test. Testing occurred on a single occasion and only one randomly selected leg of each participant was measured.

Femoral shaft torsion

Femoral shaft torsion was measured using an ultrasound-assisted method shown to have excellent intra- and inter-rater reliability. [173] Each participant was tested in supine with the hip and knees relaxed in a neutral position. Femoral shaft torsion was measured as the angle subtended by the condyles when the 'ridge' of the greater trochanter was most superficial (Figure 2). Using this previously described method, [173] a jig with an attached digital inclinometer (*Accumar* TM) was placed on the femoral condyles of the test leg. With the assistance of real time ultrasound (*Siemens ACUSON X300*), modified with a spirit level attached to the transducer, the ridge of the greater trochanter, between the insertions of the gluteus medius and vastus lateralis, was visualised. The examiner then rotated the whole leg medially or laterally until the image of the most lateral/superficial point of the ridge appeared as a 'peak' on the screen. At this point the inclinometer reading was recorded. Three recordings were taken and the average value was used for analysis. Lateral rotation of the condyles to position the ridge of the greater trochanter most superficially was termed lateral shaft torsion while medial rotation of the condyles to position the ridge most superficially was termed medial shaft torsion (Figure 2).

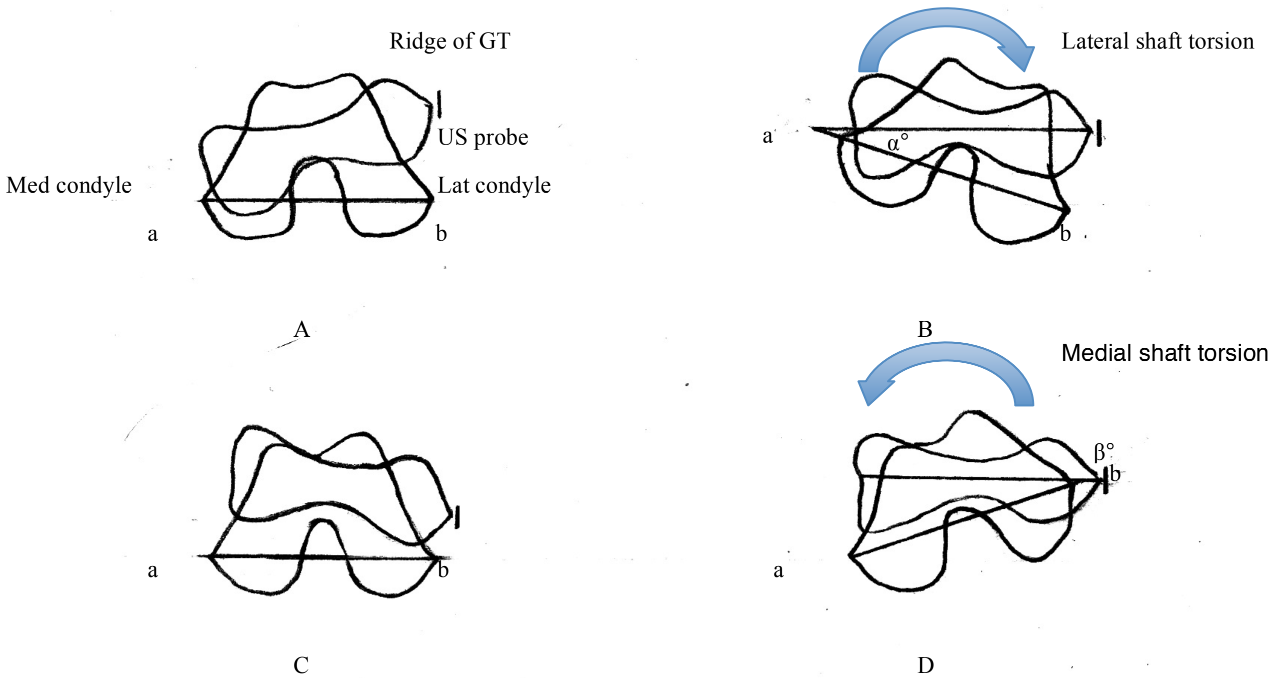

Figure 2 Schematic drawings of the measurement of femoral shaft torsion of the right hip (A) represents the starting position for a femur with lateral shaft torsion. (B) depicts the relative positions of the femoral neck and condyles when the ridge of the greater trochanter is positioned most superficially. a-b represents the axis of the distal condyles. α° represents the angle of lateral rotation of the shaft in relation to the ridge of the GtTrochanter (C) represents the starting position for a femur with medial shaft torsion. (D) depicts the relative positions of the femoral neck and condyles when the ridge on the Gt Trochanter is positioned most superficially. β° represents the angle of medial rotation of the shaft in relation to the ridge of the Gt Trochanter.

Joint position sense

Proprioception was measured using the active JPS method of reproduction of active lateral rotation of the hip. A pair of rotating discs (Fitter first; Calgary, Canada) was used for this test. Each rotating disc comprised a pair of stacked discs, the uppermost one freely able to rotate on the base disc. A large protractor was placed under the rotating discs to measure the lower limb rotational angle such that the angle subtended at the foot represented that at the hip. A two-headed arrow was drawn onto the disc to guide the participant in the placement of their foot. The anterior arrowhead was set at 0° and was aligned with the subject's second toe (Figure 3A) while the posterior arrowhead was aligned with the middle of the heel.

Participants stood on the locked rotating discs with their knees extended and their gaze straight ahead while holding onto a support (Figure 2). Both discs were locked while participants aligned their feet on the discs and found their neutral sagittal plane pelvic position. Neutral pelvic rotation was determined as the mid-point between maximum posterior and anterior pelvic rotation, and had to be maintained throughout the testing procedure. Once the test alignment had been achieved, the disc under the test leg was unlocked so it was freely movable. Participants first performed a maximum lateral rotation of their test leg on the freely moveable disc to determine their hip lateral rotation range. An average of three readings was recorded as the angle of maximum lateral rotation.

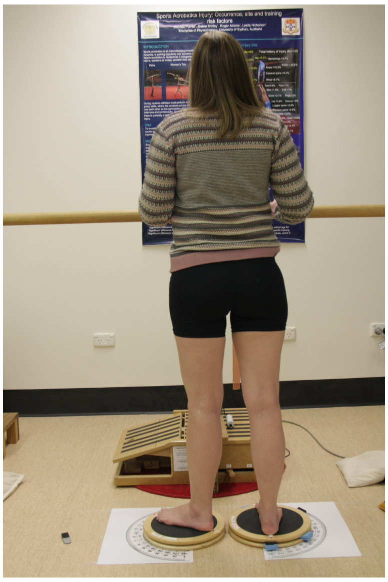

Figure 2 Participant positioning on the moveable and immoveable discs during left hip lateral rotation proprioceptive acuity testing.

Lateral rotation proprioceptive acuity was tested using a position matching paradigm at three different lateral rotation angles; 10%; inner-range (Figure 3B), 50%; mid-range (Figure 3C) and 90%; outer range (Figure 3D) of the individual's maximum lateral rotation range. The examiner turned the participant's leg via the moveable disc to one of the test angles and then returned it to the 0^{o} starting position. Participants were then asked to actively reproduce the movement to the same point in range, focussing on the position of their hip, and the angle was recorded. The participants were first instructed about the procedure for the testing, and then given three practice trials of the positioning task at each angle. The test was repeated in random order ten times for each angle, resulting in 30 position-matching trials for each participant. Participants were allowed to rest when needed.

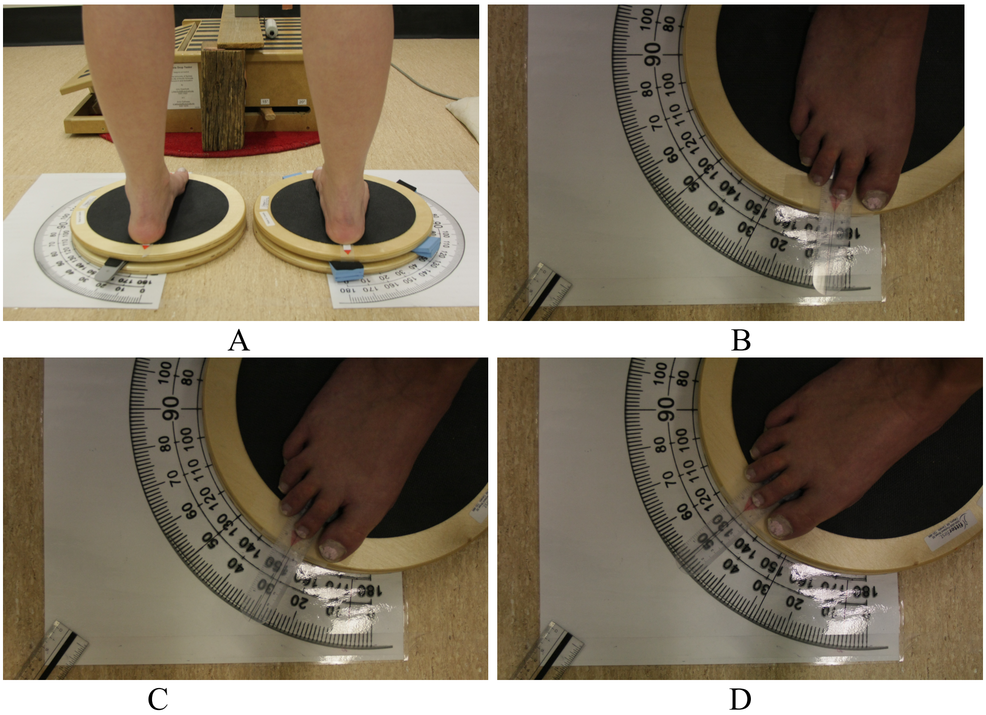

Figure 3 Examples of testing positions for one participant (A) Neutral position with second toe pointing to 0°, (B) 10% of Maximum ER (C) Mid-range/50% of Maximum ER, (D) 90% of Maximum ER.

Data analysis

Proprioceptive acuity for active joint position sense was recorded as angular error i.e the difference in angle (°) between the examiner positioned lateral rotation and the participant matched rotation. The absolute angular error was calculated as the sum of all errors divided by the ten trials for each of the three test positions. Normality testing showed that the data was normally distributed. Correlation between femoral shaft torsion and absolute angular error was analysed using Pearson's (*r*) with a level of significance set at $p \leq 0.05$. Magnitude of correlation was classified as; $r = 1$ perfect correlation, $r =$ 0.7-0.9 strong correlation, 0.4 – 0.6 moderate correlation, 0.1 – 0.3 weak and finally 0, no correlation. [174] Data were analysed using SPSS version 20.0.

Results

Mean and standard deviations for age, maximum range of lateral rotation and femoral shaft torsion for 23 females and 17 males are depicted in Table 1. A significant, weak negative correlation was found between medial femoral shaft torsion and JPS at 90% of maximum external rotation of the hip (Table 2). The greater the extent of medial shaft torsion, the smaller the absolute angular error at the 90% lateral rotation position (Figure 4A). A weak non-significant correlation was found between medial femoral shaft torsion and proprioceptive acuity at 50% of lateral rotation range (Figure 4B). At 10% of lateral rotation range, virtually no correlation was found between femoral shaft torsion and hip proprioceptive acuity (Figure 4C).

Table 1 Demographic data for age, hip rotation range and femoral shaft torsion

	Mean ± SD	Range
Age (years)	26.9 ± 7.8	19 – 55
Maximum Range of Lateral Rotation/Turnout (°)	54.1 ± 12.6	27 – 90
Femoral shaft torsion (°)	10.8 ± 5.6	0.7- 20.3

Table 2 Correlation between femoral shaft torsion and proprioceptive acuity at 10%, 50% and 90% of maximum hip external rotation

Target in an individual's lateral rotation range	10% (°)	50% (°)	90% (°)
Correlation between proprioceptive acuity and Femoral shaft torsion	*r*=0.019, p=0.909	*r*=0.116, p=0.478	*r*=-0.325, p=0.04*

*** denotes significant finding**

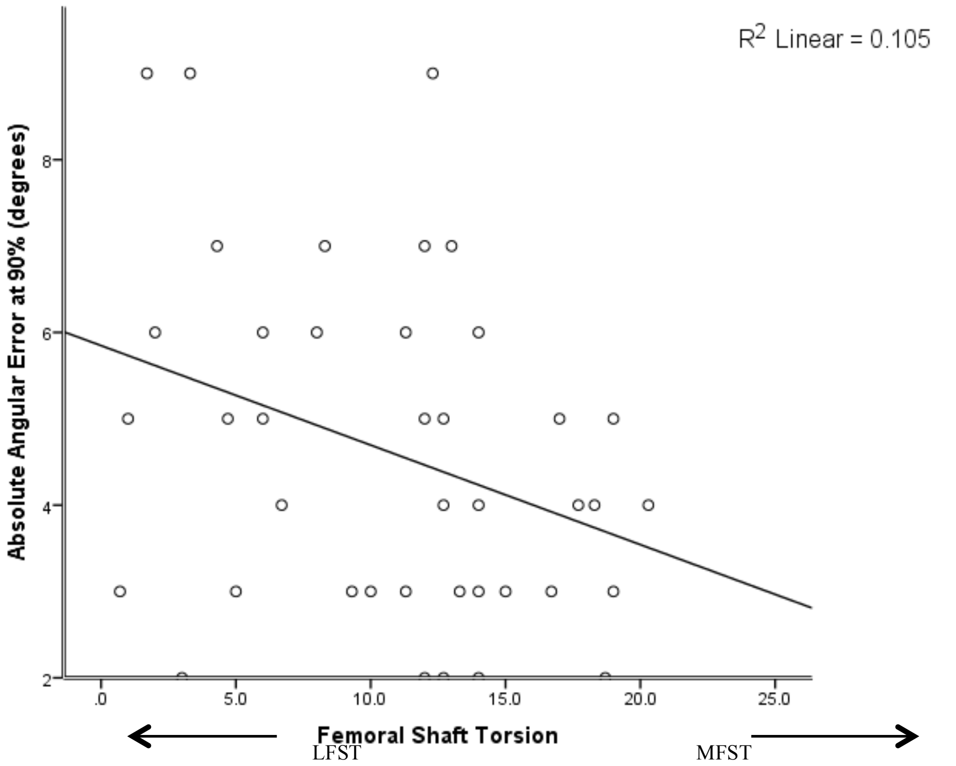

Figure 4A

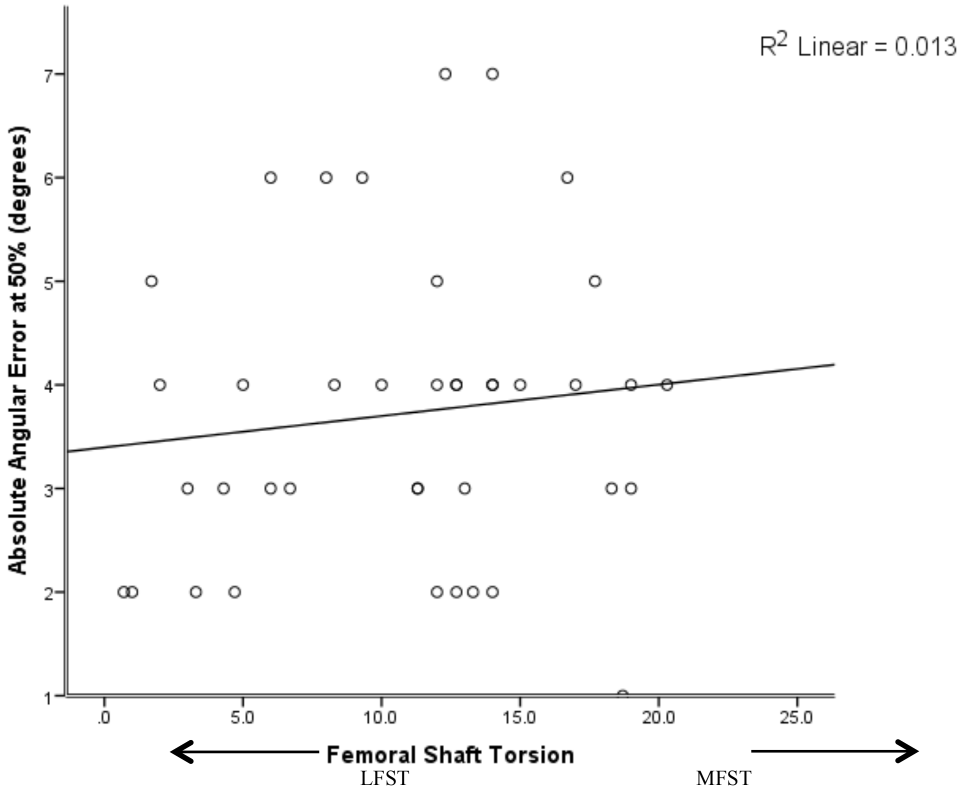

Figure 4B

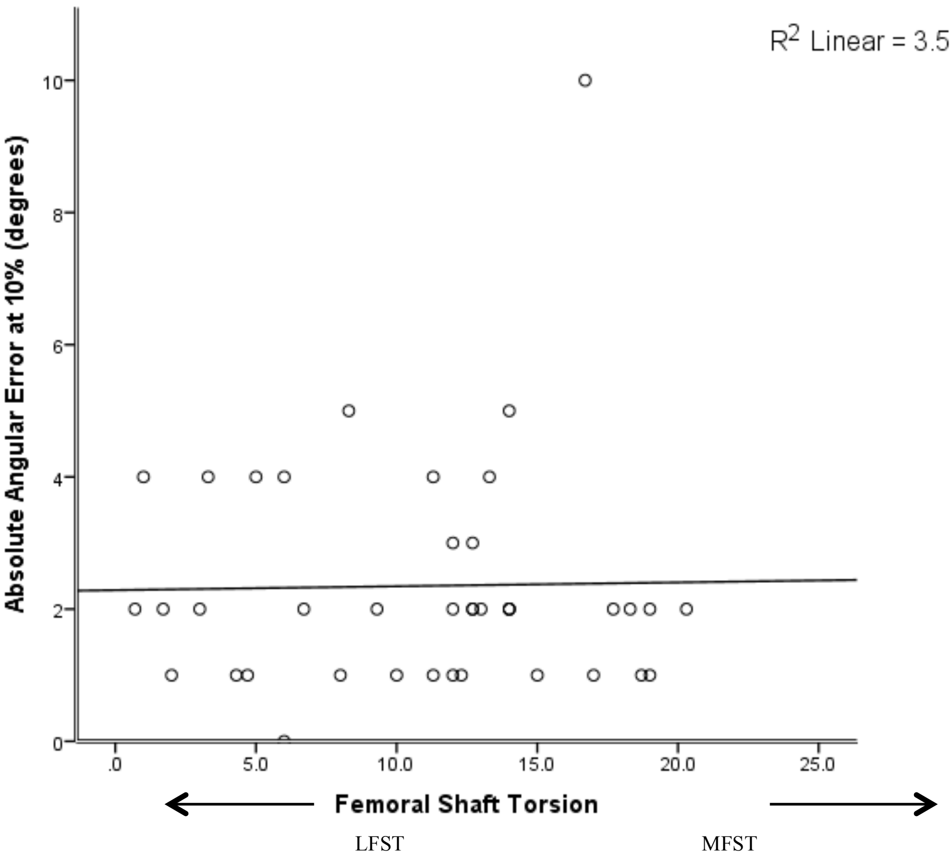

Figure 4C

Figure 4 Scatter plots showing the correlation between femoral shaft torsion (°) versus Absolute Angular Error (°) for 90% (A), 50% (B) and 10% (C)

LFST - Lateral Femoral Shaft Torsion
MFST - Medial Femoral Shaft Torsion
The lower the Absolute Angular Error, the better the proprioceptive acuity.

Discussion

This first study examining the relationship between femoral shaft torsion and active lower limb proprioceptive acuity found that hip proprioceptive acuity is better near to the maximum range of hip external rotation in people whose femoral shaft exhibits greater medial torsion. A hypothesis that may explain this relationship is the relative hip position at commencement of each trial. When the femoral shaft is medially rotated and the knee extended in standing, the lower limb is medially rotated. The patella "squints" and the foot "in-toes". Each trial started with the participant's foot pointing forward. For those participants where the femoral shaft was medially rotated, this hip position would not have been "neutral" but rather laterally rotated. This meant that their near-end of range (90% position) was achieved with less lateral rotation movement compared to participants with laterally rotated shaft of femur. Post hoc analysis of our data also showed that the smaller range of lateral rotation range is related to medial shaft torsion (r= -0.338, p = 0.03). This confirmed the findings reported that having medial shaft torsion is associated with less range of hip lateral rotation. [4, 26, 41, 122]

It is plausible that soft tissue length contributed to the better proprioceptive acuity as in the starting position on the discs the medial hip rotators would have been already lengthened. Therefore the hip lateral rotation test manoeuvre may increase the firing of the already lengthened medial hip rotators, accounting for the relationship between medial femoral shaft rotation and better hip proprioceptive acuity towards the end of lateral rotation range.

From our results little relationship was found between femoral shaft torsion and proprioception unlike the results in the shoulder [78] which prompted this study. The authors also concluded that humeral retrotorsion (lateral rotation of the distal humerus) reduced the cortical processing of the neuromuscular pathways resulting in better proprioceptive acuity during throwing as the reason for this result but it was a particularly specialised population being young elite baseball players.

The inconsistent relationship between direction of torsion and proprioceptive acuity in the lower and upper limbs might be due to several reasons; difference in sample population and difference in methods used to measure proprioception. Firstly, Whiteley et al (2008) tested elite male adolescent baseball players with considerable throwing arm retrotorsion as a result of high-load and high-frequency throwing during childhood and adolescence. Our cohort represented the normal adult population. Had we recruited elite dancers or soccer players who utilise end-range lateral hip rotation, we may have found different results.

Secondly, the different methods used to measure proprioceptive acuity between the two studies may also contribute to the conflicting findings. Our method measured proprioceptive acuity using position matching, while the study by Whiteley et al (2008) utilised magnitude estimation. [78] When proprioception is quantified using different proprioceptive measurements, no correlation has been found between the different measurements as they quantify different proprioceptive attributes. [83]

Still considering proprioception measures and one possible limitation of this study is that the task used in this study was not a discrete single joint movement. It was performed in weight-bearing with the entire lower limb involved in the task and hip movement translating down the kinetic chain to the foot where the measurement was made. Consequently information from other receptors (somatosensory and vestibular) could have affected our participants' ability to solely focus on the lateral rotation of the hip.

Another point of difference to many other studies is the measurement of femoral torsion through the shaft of the femur which does not account for torsion between the head and neck of the femur on the shaft. Although the current study suggests that excessive medial shaft torsion is related to better lateral rotation hip proprioceptive acuity, further study is warranted to examine the relationship with medial rotation and the relationship between head-neck torsion of the femur and hip proprioceptive acuity.

Clinical implications

People with lateral shaft torsion had a greater proprioceptive error near the maximum lateral rotation range. This could suggest that for people requiring good end range of lateral rotation proprioceptive acuity such as ballet dancers and soccer players, having lateral shaft torsion could be disadvantage. There may be some benefit conferred by proprioception training in this group.

Conclusion

The findings of this study suggest that medial shaft torsion is weakly to moderately associated with better lateral rotation proprioceptive acuity of hip particularly at near maximal range of lateral rotation. A weak correlation was found between the range of femoral shaft torsion and hip proprioceptive acuity at mid-range and no correlation at inner range lateral rotation.

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Faculty of Health Sciences

Publication Statement

As co-authors of the paper "Femoral shaft torsion in injured and uninjured ballet dancers and its association with other hip measures: A cross-sectional study" we have confirmed that Eliza Hafiz made the following contributions:

- concept and design of the research proposal
- data collection
- analysis and interpretation of the findings
- drafting and revising the paper and critical appraisal of content

Alison Grimaldi.. Date: 4/8/14

Elizabeth Jean Nightingale.......................... Date: 7-8-14

Claire Hiller .... Date: 6/8/14

Leslie Nicholson....................................... Date: 11/8/14

Kathryn Refshauge.................................... Date: 7/8/14

CHAPTER 5

Femoral shaft torsion in injured and uninjured ballet dancers and its association with other hip measures: A cross-sectional study

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Abstract

Background: Low range femoral torsion, termed "lateral shaft torsion", has been associated with greater range of hip external rotation and turnout in dancers. It is also hypothesised that achieving greater turnout at the hip minimises torsion at the knee, shank, ankle and foot and consequently reduces incidence of lower limb injuries.

Objectives: The primary aims were to investigate: 1) differences in range of femoral shaft torsion between dancers with and without lower limb injuries; and 2) the relationship between femoral shaft torsion, hip external rotation range and turnout. A secondary aim was to examine the relationship between femoral shaft torsion and other hip measures: hip strength, lower limb joint hypermobility, hip stability and foot progression angle, as explanatory variables.

Design: Cross sectional cohort study

Method: Demographic, dance and injury data were collected, along with physical measures of femoral shaft torsion, hip rotation range of motion and turnout. Hip strength, control, lower limb hypermobility and foot progression angle were also measured.

Results: Eighty female dancers, 50 with lower limb injury (mean±SD) 20.7 ± 4.8 years and 30 without lower limb injury (17.8 ± 4.1 years) participated in the study. There was no difference in range of femoral shaft torsion between the groups ($p = 0.941$). Femoral shaft torsion was weakly correlated with range of hip external rotation ($r = -0.034$, $p=0.384$) or turnout ($r = -0.066$, $p=0.558$). Injured dancers had a significantly longer training history than non-injured dancers ($p = 0.001$).

Conclusions: Femoral shaft torsion does not appear to be associated with the overall incidence of lower limb injury in dancers, or to be a primary factor influencing extent of turnout, in this population.

Keywords: Ballet dancers, femoral torsion, excessive medial shaft torsion, lateral shaft torsion, knee injury, ankle injury

Introduction

Femoral torsion, ante/retroversion, and ante/retrotorsion are interchangeable terms used to indicate twisting of the femur, which results in the offset of the femoral neck and condyles in the transverse plane. This torsion is a combination of bony twisting at the femoral neck and shaft. Femoral antetorsion, as characteristically found in healthy adults, refers to the 10-20º medial rotation of the femoral condyles in the transverse plane relative to the axis of the neck of femur (Figure 1).[12, 171] Medial rotation of the condyles of more than 20º is defined as excessive femoral antetorsion while less than 10º (relative lateral rotation) is termed femoral retrotorsion.[172] In children, excessive antetorsion of the femur was found to be associated with increased hip internal rotation and decreased hip external rotation range.[5, 121, 122,175] Conversely, in adult dancers, femoral retrotorsion was found to be associated with increased hip external rotation range [8]. The asymmetry in hip range due to either excessive femoral antetorsion or retrotorsion has the potential to overload the hip or joints lower in the kinetic chain, and is thought to lead to injury.[4, 5, 121, 176, 177]

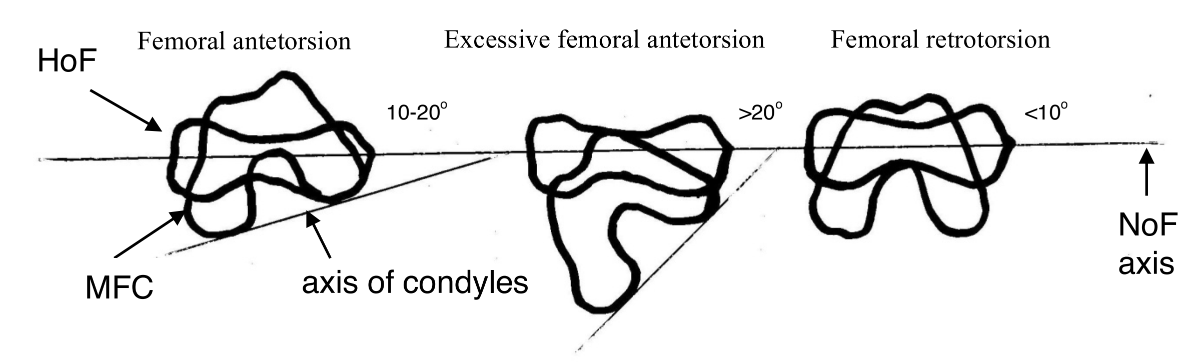

Figure 1 Femoral shaft torsion
(Superimposed head and neck of femur proximally on femoral condyles distally)
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HoF: Head of Femur proximally
MFC: Medial Femoral Condyle distally
NoF: Neck of femur proximally

Retrospective studies have shown an association between femoral torsion and lower limb injury. Eckhoff et al (1994) found that excessive femoral antetorsion (defined as more than 15º) was associated with anterior knee pain and arthritis in adults. [104, 105] Discrepancies between the rotational tolerance of the hip joint and that of the knee joint in the antetorted femur result in significant increases in patellofemoral contact pressure[120] explaining the association with pain.[104] The same researchers found that femoral retrotorsion, defined as an angle less than 10º, was associated with hip arthritis and instability.[105] However, femoral torsion as a causal factor for lower limb pain or injury has yet to be demonstrated in a prospective study.

In the upper limb, retrotorsion of the humerus has been found in throwers' dominant arms, which is believed to be due to the effect of repetitive mechanical loading on the humerus.[178, 179] In the lower limb, repetitive turnout manoeuvres in ballet may be analogous to repetitive throwing in the upper limb. Although no studies have shown that ballet training can influence the amount of torsion of the femur, it has been theorised that early ballet training and high training intensity may affect skeletal modelling, allowing for a moulding of femoral torsion up to the ages of 11 to 14 years. [180-182] The proximal femoral physes close at approximately 17 to 18 years and the distal femoral physes close at approximately 17 to 19 years.[183] Therefore, it can be speculated that intense ballet training, even at a later age (up to 20 years) may affect the skeletal modelling of the femur.

In children, retrotorsion of the femur was shown to be associated with increased range of external rotation which potentially optimised the execution of ideal turnout with minimal involvement of the knee, tibia and ankle and hence potentially decreased the susceptibility of developing lower limb injuries.[40, 184-187] Ideal turnout (180^{o}) is optimally achieved through maximal hip external rotation, with less contribution from the knee, ankle and foot.[182, 188] Thomasen et al suggested that in order to produce the ideal turnout, each joint should contribute; 70^{o} passive hip external rotation, 5-10º of tibial external rotation, and 15-20° of movement of the foot. [95] Based on this proposal, dancers with femoral retrotorsion should have a lower risk of developing lower limb injuries. Dancers with less hip external rotation, and possibly excessive femoral antetorsion, attempt to increase turnout angle by planting their feet in position through excessive motion at the knee and foot [95]. These compensatory strategies at the knee and ankle can lead to altered loads throughout the lower limb thereby increasing the risk of injury to the lower limb.

Previous studies used a conventional method to measure femoral torsion whereby torsion of the femur was identified as the angle subtended by the axis of the head-neck and the condyles of the distal femur. However, the actual site of torsion remains unknown. Torsion may occur at one of two sites: between the femoral head and neck, or between the greater trochanter and shaft, or may occur at both sites during growth. Therefore, the primary aims of this study were to investigate: (i) femoral shaft torsion in dancers with and without lower limb injury, (ii) the relationship between femoral shaft torsion and passive hip external rotation range and turnout. The secondary aim was to investigate the association between femoral shaft torsion and other measures including strength, lower limb hypermobility, foot progression angle and hip stability.

Methods and Participants

For this cross sectional study, 80 female professional dancers and tertiary level dance students, with mean age 19.6 ± 4.7 (mean±SD) years, were recruited from performing arts schools in the Sydney Metropolitan, Canberra, Brisbane and Wollongong areas in Australia. Inclusion criteria were: female, aged between 14 and 35 years, a history of at least four years of ballet training in their childhood or adolescence but may or may not be currently dancing (of any type). The four-year minimum was chosen since four years of ballet training has been previously observed to affect skeletal modelling.[8] Dancers were excluded if they had a history of hip surgery, any lower limb congenital disorders, or any current injury that would limit testing.

Injury status determined group allocation. Group 1 was comprised of injured dancers who had either a current lower limb injury or a history of lower limb injury (n=50). Only dance-related injuries diagnosed by a clinician (physician or physiotherapist) were included and reported in this study. Group 2 were dancers (n=30) with no history of dance-related injury to the lower limb. Approval for the study was granted by the University of Sydney's Human Research Ethics Committee (2012/577). Informed consent was obtained from all dancers, and for dancers younger than 16 years a parent or guardian also provided consent.

Only one leg of each dancer was tested in a single session (22 left and 28 right in the injured group and 19 left and 11 right in the non-injured group). Testing was undertaken on the injured leg of unilaterally injured dancers or the leg with the injury that took the longest time to recover, ie. return to dance, in dancers with bilateral injuries. The test leg was randomized in the uninjured dancers. Each test was performed three times and the average of the three was used for statistical analysis, except for strength testing for which the best performance of the three trials was used.

Measurement Protocol

Questionnaires

Demographic data and information about dance history and injury history were collected. Subjects were broadly matched for age. Demographic questions included: age at the time of testing and menarche. Questions on dance history included: age commenced dancing, total years of dancing, hours of dancing per week, types of dancing studied at the time of testing, hours of ballet training per week (if still currently dancing), total years of ballet training, grade of ballet reached, and type/s of ballet studied. Questions on current and previous lower limb musculoskeletal injury history included: area, side (right or left), type of injury, when the injury occurred, ability to dance during the recovery period (severity of the injury in yes/no), time taken to recover (full resumption of training) was also asked, and whether the injury had any current effect on dancing.

Physical measures

Femoral shaft torsion

In the current study, measurement of femoral torsion using an ultrasound-assisted method was confined to the femoral shaft using a method previously developed by the authors. [173] This method was shown to have excellent intra- and inter-rater reliability. [173] Briefly, the dancer lay supine with their hips and knees relaxed in a neutral position. A customised jig with an attached digital inclinometer (*Accumar* ™) was aligned with the femoral condyles of the test knee. With the assistance of real-time ultrasound (*Siemens ACUSON X300*), the assessor produced an image of the greater trochanter 'peak'. [173] The assessor ensured that the transducer was maintained in the coronal plane using the attached spirit level after which the whole leg was rotated internally (medially) or externally (laterally) until the 'peak' appeared uppermost on the screen. The angle of femoral shaft torsion was defined as the angle measured on the inclinometer representing the relative position of the axis of the condyles to the greater trochanter. Medial shaft torsion was defined as medial rotation of the condyles and lateral shaft torsion as lateral rotation of the condyles relative to the most superficial placement of the "peak".

Hip rotation range of motion

Hip rotation range was measured using a digital inclinometer with the dancer lying prone. With the hip in neutral flexion/extension and neutral abduction/adduction, the dancer's knee was passively flexed to 90° and the inclinometer was placed on the tibia just proximal to the medial maleolus.[189] The assessor used the shank to produce passive hip internal and external rotation until the contra-lateral pelvis was observed to move. Maximum hip external and internal rotations were measured separately.

Turnout

Active turnout was measured with the dancer standing, with each foot on a rotational disc (Fitterfirst; Calgary, Canada) placed on an enlarged protractor (Figure 2).[190] The diameter was drawn across each disc, and marked with an arrowhead at each end. The anteriorly-pointing arrow head was aligned with 0^{o} on the protractor and with the dancer's second toe. The posteriorly-pointing arrow head was aligned with the middle of the dancer's heel. The dancer stood with their knees straight and their pelvis in a relaxed self-selected position. Full external rotation of the hip (turnout) was performed actively on both legs but only the angle of turnout of the test leg was recorded. The tester watched for any compensatory strategies, such as anterior pelvic tilt, and the dancer was asked to immediately correct their posture.

Figure 2 Turnout measurement

Other physical measures

Hip Strength

Strength of the hip flexor, extensor, abductor and adductor muscle groups was measured using the 'break' method where maximum isometric contraction produced by a muscle group was overcome by a force applied by the examiner [191, 192]. The hip flexor and adductor muscle groups were tested with the dancer in supine and the hip and knee of the tested leg at 90°. The hip extensor muscle group was tested in prone and the abductor muscle group was tested in side lying with the test leg uppermost. Both extensor and abductor strength were tested with the test knee in extension. Strength was tested using a hand-held dynamometer (*Lafayette Instrument*) which is a reliable method for muscle strength testing in a clinical setting [193]. Dancers could stabilise themselves by holding on to the side of the table with their hands. The dynamometer was placed 5 cm proximal to the superior border of the patella for flexion, the lateral knee joint line for abduction, the medial knee joint line for adduction and the posterior knee crease for extension. The dancer was asked to perform a 5 sec maximal isometric contraction. Each dancer performed three repetitions for each muscle group. The average of three readings was used for analysis.

Lower Limb Hypermobility

The lower limb assessment scale (LLAS) was used to quantify general hypermobility of the lower limb. This is a 12-item test with a maximum score of 12. Excessive movement on eight or more items indicated hypermobility.[194] Only the test leg was assessed.

Foot Progression Angle

Foot progression angle (FPA) was computed based on the method described by Shores.[195] The sole of the dancer's test foot was coloured with water-based paint. The dancer was then instructed to walk along an 8m sheet of paper at normal walking speed. Five foot prints were obtained, and the FPA was computed using the second, third and the fourth prints of the test leg. Computation of the FPA required dividing the foot into thirds (Figure 3). A line was drawn marking the lowest third segment of the foot (CD). A line was also drawn from the second toe to the middle of the heel (AJ). The point where these two lines intersect was marked (F). FPA was the angle made by the longitudinal line connecting the point of intersection from the second and third footprints and repeated for all four footprints. An average foot progression angle of three steps of the test leg was calculated.

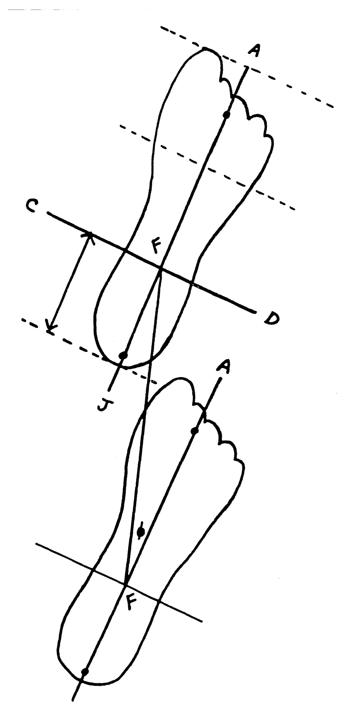

Figure 3 Computation for foot progression angle

Figure adapted from Shores et al (1980). [195] AJ: Foot length, CD: ⅓ of foot length and ϕ: the angle of foot progression

Hip Motor Control

Hip motor control was measured using the lateral pelvic drop test based on the test described by Weir et al, 2010.[196] Dancers stood on the edge of a step with their pelvis and shoulders parallel to the ground and hands on the waist. The non-test limb hung over the side of the step with the foot in plantar grade. To ensure that the movement was focussed on the hip, both knees remained straight while dancers lowered their non-test leg towards the ground and maintained their shoulders in the starting position. Successful achievement of the test was to lower and return the non-test limb to the starting position without implementing compensatory strategies. A mirror provided visual feedback. A metronome was used to standardise the rate of lowering and raising of the non-test leg. Dancers were instructed to perform as many repetitions as they could or until the test ended after 60 sec. Markers were placed on both anterior superior iliac spines to facilitate observation of any compensatory strategies. Compensatory strategies, which were recorded as a failed test, were: inadequate hip raising, hip hitching, bending the stance knee, or hip/trunk sway in any direction. Dancers were told to correct their posture, should there be any compensatory movement detected, before continuing the test and were instructed to stop after three failures were recorded. The number of successful repetitions (1 full cycle of lowering and raising) was recorded.

Data analysis

Data were analysed using SPSS version 20.0. Descriptive statistics were used to summarise the group data. Differences between the injured and uninjured groups were analysed using independent t-tests. The significance level was set at $p = 0.05$. Correlations between femoral torsion and hip external rotation, turnout and other measures were reported using the two-tailed Pearson correlation coefficient. The strength of the correlation was interpreted based on the classification of Hastings whereby *r* values between 0.00 to 0.19 were interpreted as very weak, 0.20 to 0.39 as weak, 0.40 to 0.50 as moderate, 0.60 to 0.79 as strong and 0.80 to 1.0 were interpreted as very strongly correlated. [197]

Results

Demographic data and physical measures

Table 1 summarises participants' demographic characteristics, dance history and all physical measures; femoral shaft torsion, hip range of motion, turnout, hip strength, lower limb hypermobility scale, hip motor control and foot progression angle. Most dancers (92.5%) were currently engaged in dancing. Styles included: ballet only (7.5%), combination of ballet and other types of dancing ie contemporary, jazz (85%), and other types of dancing excluding ballet (7.5%). Most dancers (62.5%) achieved a minimum of Royal Academy of Dance (RAD) intermediate foundation grading.

Table 1 Demographic and physical measures data, mean (SD) for dancers (N=80)

	Injured (n=50)	Non-Injured (n=30)	P Value
Age (years)	20.7(4.8)	17.8 (4.1)	0.216
Age of menarche (years)	12.7 (4.1)#	12.2 (3.5)#	0.408
Age started dance (years)	5.7 (3.3)	5.7 (3.5)	0.426
Years of dancing	14.3 (5.7)	11.6 (4.3)	0.104
Years of ballet training	12.1 (6.2)	9.6 (3.7)	0.001*
Hours of dancing per week	18.8 (13.3)	16.8 (12.3)	0.266
Hours of ballet per week	8.3 (10.5)	9.6 (3.7)	0.399
Femoral torsion (°)	12.3 (6.3)	13.4 (6.8)	0.941
Hip rotation (°)			
External rotation	53.0 (11.9)	48.7 (10.7)	0.536
Internal rotation	38.0 (9.4)	41.0 (10.4)	0.356
Turnout (°)	60.0 (10.9)	61.2 (12.1)	0.778
Hip strength (kg)			
Flexors	16.9 (3.7)	16.0 (3.5)	0.638
Extensors	13.0 (4.0)	13.9 (4.2)	0.728
Abductors	14.1 (3.5)	14.2 (3.4)	0.887
Adductors	11.0 (2.8)	11.4 (3.2)	0.672
Lower limb assessment scale	6.9 (2.4)	6.0 (2.6)	0.001*
(y/n)	19.3 (12.5)	20.5 (8.9)	0.174
Hip motor control (reps)	9.0 (4.5)	7.9 (4.7)	0.867
Foot progression angle (°)			

 # Missing data from six dancers who had not reached menarche at the time of testing
*** Significant at $p<0.01$**

There was no difference in the magnitude of femoral shaft torsion between injured and non-injured dancers (p = 0.94). Average femoral shaft torsion of all dancers was

12.7°±6.5° (mean±SD); 76% had lateral and 23% medial shaft torsion. Only 1% had neutral/zero femoral shaft torsion (0°). The average torsion for injured dancers was 12.2° (6.3°) and for non-injured dancers was 13.4° (6.8°).

Injury data

Injuries involving multiple joints were reported by 34% of injured dancers, ankle injury only by 24%, and knee injury only was reported by 10% of injured dancers (Table 2). The most common specific pathological diagnosis was ligament sprain (17.2%), followed by muscle strain (12.5%) and compartment syndrome (12.5%, Table 3). Fifty per cent of those injured continued to dance immediately following the injury. Most injured dancers (78%) currently experienced ongoing symptoms from their injury such as instability, weakness, pain or discomfort. Injury incidence was significantly higher in dancers with longer participation (mean±SD) 12.1±6.2 years than those with shorter participation 9.6 ±3.7 years, $p < 0.001$ in ballet training and those who had a higher hypermobility score on the LLAS (Table 1), $p < 0.001$

Table 2 Injury by anatomical site (N=50)

Injury	**N**	Percentage of the injuries (%)
Combination[α]	17	34
Ankle	12	24
Knee	5	10
Shin/calf	5	10
Foot	4	8
Other[β]	4	8
Hip	3	6
	50	**100%**

α denotes injury to a combination of: foot ankle & shin, shin & hip, ankle & hamstring, ankle & lower back, knees & ankle, knee, ankle, hip & back, hip, adductors & hamstring, ankle & shin, hip & knee, knee & SIJ, patella & hamstring, ankle, hamstring & knee and hip & hamstring

β denotes injury to either patella **or** tendon (achilles & tibialis anterior)

Table 3 Injury type by diagnosis

Type of injury	N	Prevalence of injury (%)
Others e.g; Sesamoiditis, laceration, subluxation	14	22
Ligament Sprain	11	17
Muscle strain	8	13
Compartment syndrome/shin splints	8	13
Stress fracture	7	11
Dislocation/subluxation/displacement	6	9
Tendonitis	4	6
Patellofemoral pain	4	6
Osgood Schlatter's disease	2	3
	64	**100%**

Relationship between femoral shaft torsion and other variables

Femoral shaft torsion was found to have a very weak, negative correlation with range of hip external rotation (r = -0.034, p=0.384) and turnout (r = -0.066, p=0.558). The association between femoral shaft torsion and all other variables was also found to be very weak (Table 4).

Table 4 Correlation between femoral shaft torsion and other measures

	Femoral torsion *r* (*p value*)
External rotation	-0.034 (0.384)
Internal rotation	0.042 (0.356)
Turnout	-0.066 (0.558)
Flexion strength	0.140 (0.108)
Extension strength	-0.041 (0.358)
Abduction strength	0.090 (0.214)
Adduction strength	0.021 (0.428)
Lower Limb Assessment Scale	-0.025 (0.413)
Foot Progression Angle	-0.112 (0.162)
Lateral pelvic drop	-0.102 (0.184)

Discussion

We found no significant difference in magnitude of femoral shaft torsion between dancers with a history of lower limb injury and those without. We also found that magnitude of lateral shaft torsion was not correlated with range of hip external range of motion or turnout or with any other variables evaluated in this study. To our knowledge, this study is the first to investigate the relationship between femoral shaft torsion and lower limb injury in dancers.

Despite retrospective studies showing an association between femoral torsion and lower limb injury,[104, 105, 115, 116] no association was found in the current study. This may be for two methodological reasons. Firstly, we included all types of lower limb injuries rather than considering specific injuries, whereas previous studies examined the relationship between femoral torsion and specific injuries, such as anterior knee pain, [104, 105] knee osteoarthritis [115] or hip osteoarthritis independently. [116] Work in the area suggests that different hip characteristics cause different types of injury. Excessive range of hip external rotation has been shown to cause lower limb stress fractures. [128, 129] The current study was not powered to investigate these direct relationships and examined all types of lower limb injury. It may be that excessive medial shaft torsion is more related to knee and ankle injuries, due to the potential rotational stresses developed when attempting to achieve turnout.

Secondly, the method of measuring femoral torsion used in previous studies differed from the method used in our study. We measured femoral shaft torsion while other studies measured total femoral torsion. It is possible that the femoral shaft torsion measure is less representative of the total torsion than that occurring at the physes/neck. However, the femoral shaft torsion in our cohort, 12.7° (6.5), is similar to the range of femoral torsion reported in other studies of dancers. [8, 101, 198-200] Future work could also concentrate on calculating total torsion occurring down the lower limb, incorporating torsion measures throughout the femur, the orientation of the acetabulum and torsion of the tibia. Thirdly, previous studies recruited an older population (21-84 years), whereas we recruited participants aged 14 to 35 years. It is possible, although unlikely, that femoral modelling continues after closure of the physes, usually between 17 and 19 years old. [183]

Although our study showed no difference in femoral shaft torsion between injured and non-injured dancers, we found that injured dancers had a longer history of participation in ballet training and had greater hypermobility (LLAS) than non-injured dancers. The current study was not designed or powered to investigate the relationship between length of dance history and the rate of injury, however our secondary findings confirm those of others.[153, 201] Normative data on hypermobility, based on LLAS, are from children and are not available for adults however hypermobility is expected to decrease with age; therefore adult scores on the LLAS may be expected to be lower, as was found in this study, than in children. Nevertheless, our data suggest that hypermobility is significantly different between groups and may therefore contribute as a risk factor for injury in dancers. Further longitudinal research is required to confirm or refute this hypothesis. This current study found a very weak correlation between magnitude of femoral shaft torsion and turnout in adults despite previous research demonstrating a strong relationship in children.[5, 121, 122] McHay et al, (2000) theorised that dancers may develop retrotorsion of the femur (equivalent to lateral shaft torsion in this study) as a result of repetitive turnout training, in conjunction with forces involved in ballet manoeuvres such as jumping and landing,[202] which are known to alter bone modelling in the hip region during the pre-pubertal period.[203-206]. Hamilton et al [8] reported a moderate negative correlation between femoral antetorsion and turnout. However, the clinical method used to measure femoral torsion was later found to be inaccurate when compared against the gold-standard of MRI.[207] The current study measured femoral shaft torsion, a different aspect of femoral torsion and this possibly also contributes to the inconsistent findings.

We also found that turnout did not correlate well with passive range of hip external rotation, suggesting that dancers in our study achieved their turnout in different ways, including for some dancers, predominantly at the knee and/or the ankle. Chronic compensatory manoeuvres for producing maximal external rotation of the hip and turnout may result in injuries to these distal joints on the same extremity [101] and perhaps affect skeletal modelling of the tibia. Future research could measure tibial torsion and examine the relationship between tibial torsion and range of hip external rotation, turnout and lower limb injury.

Dancers' range of hip external rotation in the present study was similar to that reported in other dancers, and is significantly higher than that of non-dance populations at the same age. Also, despite having greater range of hip external rotation than the non-dance population, femoral torsion in dancers is not significantly different. [8, 101] The greater range of hip external rotation could be due to greater flexibility of the hip joint passive structures, [182, 208, 209] hip rotation strength, or shortening of the hip external rotators and posterior hip joint capsule with a concomitant lengthening of the hip internal rotators and the anterior capsule. [34, 40, 43, 182] Future studies could consider the correlation between femoral shaft or total torsion and strength of the hip rotators.

Our secondary aim was to investigate whether there was any relationship between femoral shaft torsion and other hip measures. We found only very weak correlations between femoral shaft torsion and muscle strength, lower limb hypermobility, hip stability and foot progression angle.

Conclusion

This study found no difference in femoral shaft torsion between dancers with and without lower limb injury. Lateral shaft torsion measured using real-time ultrasound was found to be very weakly correlated with hip external rotation and turnout in this cohort. No clinically relevant correlations were found between femoral shaft torsion and other hip measures.

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CHAPTER 6

CONCLUDING REMARKS

Synthesis of findings:

The systematic review performed as part of this thesis aimed to investigate whether a relationship exists between any hip characteristics and lower limb injury. Despite retrospective studies suggesting a relationship between excessive antetorsion/medial shaft torsion and knee pain [1, 2] no study had examined this prospectively to determine causality. Hip rotation range of motion and strength in external rotation and abduction are suggested as factors potentially implicated in a variety of lower limb injuries, however, these factors are dependent on the injury being considered and the plane of motion being considered. Furthermore, due to the small number of studies found and the majority of these not having large sample sizes the relationships between hip characteristics and lower limb injury required further investigation.

Understanding femoral torsion and where it occurs in the femur is needed to provide information to clinicians as to whether excessive range of femoral torsion can be a cause of injury particularly to the lower limb, due to the compensatory strategies adopted by the structures distal to the hip. However, before the relationship can be investigated, a reliable method to measure femoral shaft torsion using real time ultrasound with standardised bony landmarks needed to be developed. Subsequently, the newly developed method was used to measure the range of femoral shaft torsion that was used across the studies presented in this thesis.

Femoral torsion, hip rotational range and strength are often thought to influence proprioception, as has been found in the humerus. In the upper limb, humeral retrotorsion was found to be associated with better shoulder proprioceptive acuity which was subsequently found to reduce the risk of shoulder injuries in throwing athletes. However femoral shaft torsion measured in this thesis was not found to be associated with lower limb injury in dancers, or with a range of hip measures, and only weakly correlated with active proprioceptive acuity in the outer range of hip external rotation.

The association between hip characteristics and the range of injuries experienced in dancers was explored in the cross sectional study, with this study population chosen particularly for their hip positioning during turnout maneuvers from a very young age. Positioning the hip into a constant turned out position was hypothesised to influence the degree of femoral torsion in this population. However, no difference was found in the range of femoral torsion between injured and non-injured dancers. Neither were any clinically relevant correlations found between the range of femoral torsion and other hip measures.

Measuring femoral shaft torsion

Measuring the true range of femoral torsion in vivo has been a debated issue amongst researchers particularly due to the complexity of most methods. CT Scan is deemed as the most accurate method but the exposure to high levels of radiation limit its usage, especially in paediatrics. MRI imaging provides similar results to a CT Scan, however the equipment required precludes its use in the clinic and the costs are very high. Alternatively, the usage of real time ultrasound was developed in the late 80s and is free from radiation.

Femoral torsion has traditionally been measured with ultrasound using the angle between the axis of the head and neck of the proximal femur and the posterior condyles of the distal femur. Although ultrasound measurement of femoral torsion using a conventional description of the head and neck has been shown to be reliable and valid when compared to MRI. [3, 4] its usage has been proven to be highly dependent on the operator and with poor inter-rater reliability. [5] The new method was primarily developed to reduce measurement errors by utilizing standardised easily imaged and identified landmarks. While the actual site/s of torsion remains unknown, it is thought to occur two sites: between the femoral head and neck, and/or between the greater trochanter and the condyles. To shed light on this, a method of measuring femoral shaft torsion was developed that was simple and easy to administer in the clinic setting.

Measurement of femoral torsion using real time ultrasound has traditionally been administered using non-standardised landmarks. As suggested by Naredo et al, establishing a standardization of scanning methods and accurate definition of the landmarks should increase the reliability of ultrasonography usage in musculoskeletal imaging.[5] The new technique identified proximal and distal landmarks that were easily located, and standardised using a method designed to ensure consistent positioning of the real time ultrasound probe and a condylar jig. While RTUS usage is highly dependent on the operator, the new standardised technique should reduce the error of measurement that may be caused by the operator. The excellent reliability of the simple, non-invasive, and relatively inexpensive method for measuring femoral shaft torsion allowed the investigation of the relationship of this measure to lower limb injury and other hip measures. Although the newly developed method has excellent reliability, future studies should be undertaken to examine the validity of the new method by comparison with the "Gold Standard"; MRI.

Femoral shaft torsion and lower limb injury

The systematic review performed as part of this thesis found no prospective research examining the relationship between femoral torsion and lower limb injury. This was despite retrospective studies which suggested a relationship between excessive antetorsion/medial shaft torsion and knee pain.[1, 2] As these studies used a 'total' torsion measure, the examination of femoral shaft torsion could have further elucidated the relationship.

Habitual activities which put a rotational stress through the femur from an early age, such as cultural sitting positions (reverse tailor position or crossed legged sitting on the floor) [6] or ballet training[19] have been shown to affect the amount of femoral torsion developed. Dancers may develop a greater range of torsion due to the prolonged stance in turnout, which fixes the feet at an angle of up to 90 degrees from the anatomic stance position. Therefore it may be expected that if an effect of femoral shaft torsion could be found, dancers would be a likely population.

The incidence of lower limb injuries is high, not just in the sporting population but also in the dance population.[7, 8] The high occurrence of these lower limb injuries in the dance population was speculated to be due to the lack of available range of hip external rotation associated with excessive femoral antetorsion/medial shaft torsion[9, 10]. If excessive torsion is present it was hypothesized to lead to compensatory strategies and stresses on structures distal to the hip.

Surprisingly there was no difference in femoral shaft torsion measured in dancers with a history of lower limb injury and and non-injured dancers. It was therefore concluded that femoral shaft torsion was not associated with lower limb injury in dancers. These findings also suggest that training into forceful hip external rotation and turnout since a young age, which was suggested to have potential for affecting bone architecture,[11] did not affect torsion in the shaft in our population and therefore cannot be considered as a contributing factor to lower limb injury in these dancers. However, the cohort of dancers used in the study may have not have trained enough or to a high enough level, to have developed significant femoral retrotorsion. Future research could follow a cohort of skeletally immature dancers to maturity and/or a cohort of previously uninjured dancers to determine whether femoral shaft torsion predicts lower limb injury.

This thesis focused on measuring femoral torsion at the shaft of the femur and not at the head and neck. Measuring femoral torsion at the head and neck may identify an association with lower limb.

The type of lower limb injuries investigated in this thesis was perhaps too general. Examining the relationship between femoral shaft torsion and specific injury to the knee may be reveal association and therefore be worthwhile investigating.

The results from chapters 3, 4 and 5 suggested that while torsion could be reliably measured, shaft torsion may not be the cause of lower limb injury. However, from the systematic review greater range of hip rotation and greater hip external rotator and abductor strength were found to increase the risk of sustaining lower limb injury such as stress fracture in military recruits [12, 13] medial tibial stress syndrome in adolescent runners, [14] and patellofemoral pain in runners and naval recruits.[15, 16] The strength of these finding however are unknown or imprecise due to the variety of the populations studied. Therefore, the results should be accepted with caution.

The dance literature strongly suggests limited turnout affects the development of lower limb injury in dancers. [9, 17, 18] While femoral torsion is discussed as one factor which may contribute to this, other suggested factors are external rotation range, external rotation strength, and hip morphology. [10, 11] The results of the dance population studied here do not support these thoughts in regards to external hip rotation range and strength, although this could equally be due to the population studied and the wide range of included injuries.

Femoral shaft torsion and other measures

An analysis of association between femoral shaft torsion and other hip measures was explored but did not find any links except for a weak association between proprioception and torsion. Proprioceptive information is necessary for neuromuscular control of the dynamic restraints therefore provides a unique sensory component to optimize motor control [19] therefore possibly preventing injury to the joint. The relationship between femoral shaft torsion and hip proprioceptive acuity was investigated in normal healthy adults and medial femoral torsion was only found to be weakly correlated near to the maximum external rotation range and not at angles closer to internal rotation and at mid range. While this lack of relationship meant we decided not to use the active joint position matching in our dancer cohort, it may be that acuity is different in an injured population.

Proprioceptive acuity in this thesis was measured using active joint position matching by reproduction of active movement; one type of modality used in determining proprioceptive acuity of the joint. It has been shown that results for proprioception are different when measured using different modalities.[20] Therefore, other submodalities such as kinesthesia or sense of resistance or heaviness may have a relationship with femoral shaft torsion. Also, the proprioceptive measure used in this thesis involved the contribution of the knee and ankle joints tested only on one leg. It is almost impossible to measure hip proprioceptive acuity in weightbearing in isolation from the knee and ankle. The involvement of the joints distal to the hip and their associated muscle ligament and joint proprioceptors, may compensate for any proprioceptive deficit at the hip.

Although the aim of the proprioception study was not to determine the relationship between femoral shaft torsion and the range of hip external rotation, post hoc analysis of our data also showed that a smaller range of external rotation is related to medial shaft torsion. This confirmed previous findings which reported that having medial shaft torsion is associated with decreased range of hip external rotation.[21-23] Interestingly however the same relationship was not found in the study with the dance cohort. This could be due to adaptation of the structure around hip and the knee to through compensatory strategy adopted to develop more hip external rotation range for perfect turnout.

Clinical implications:

The clinical implications of the body of work contained in this thesis are:

1. The development of the newly developed method is reliable and can be easily and quickly administered in the clinical setting with minimal training.
2. The method can be utilized in place of high radiation or time consuming imaging techniques for pre-surgical evaluations in hip and femoral surgery.

3. Future investigations of the importance of the site and role of torsion in the femur will be easy and cheap and may be possible to carry out in a clinical setting.

Directions for future research:

There are a number of directions for future research arising from this thesis. Firstly, the novel method of measuring femoral shaft torsion developed in this thesis should be used alongside the conventional method to determine the total range of femoral torsion. That is, future studies should measure torsion at both the femoral neck and at the shaft. Ability to measure the amount of torsion at different sites along the femur may lead to the establishment of the nature of development of femoral torsion. This knowledge would, in turn, improve our understanding of the forces placed across the femur during development and activity. In addition, the newly developed method was only used in the cross-sectional study, presented as part of this thesis, therefore causality and change cannot be inferred. A longitudinal study using the newly developed method and/or the conventional method is warranted to provide an answer as to whether femoral torsion is a predictor to lower limb injury.

Secondly, although this thesis concluded that there is no association between femoral shaft torsion and lower limb injury, the lower limb injuries considered in this thesis were limited to injuries distal to the hip. Perhaps, femoral shaft torsion may be associated with injury to the hip itself or to discreet structures such as the knee. Alternatively, it could reasonably be argued that femoral shaft torsion is not a factor in lower limb dance injuries, and effort should be expended on other variables such as hip rotation range, hip strength, or tibial torsion.

Conclusion

It has become clear that determining the impact of femoral torsion is challenging and complex. However, the findings of this thesis have led to a better understanding of the role of torsion in the femoral shaft. In summary, the studies undertaken in the production of this thesis have shown that femoral shaft torsion should not be considered as a factor that will likely predispose dancers to the development of lower limb injury. Femoral shaft torsion is also not a factor associated with hip rotation range and turnout. Future work should focus on other aspects of femoral torsion and hip factors that may relate to lower limb injury.

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APPENDICES

APPENDIX B: KNEE SURGERY, SPORTS TRAUMATOLOGY AND ARTHROSCOPY

Manuscript Submission

Submission of a manuscript implies: that the work described has not been published before; that it is not under consideration for publication anywhere else; that its publication has been approved by all co-authors, if any, as well as by the responsible authorities – tacitly or explicitly – at the institute where the work has been carried out. The publisher will not be held legally responsible should there be any claims for compensation.

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The Journal asks authors to assign a level of evidence to all clinically oriented manuscripts.

- Levels of evidence (definition) (pdf, 15 kB)

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The title page should include:

- The name(s) of the author(s)
- A concise and informative title
- The affiliation(s) and address(es) of the author(s)
- The e-mail address, telephone and fax numbers of the corresponding author

Abstract

Please provide a structured abstract of 150 to 250 words which should be divided into the following sections:

- Purpose (stating the main purposes and research question)
- Methods
- Results
- Conclusions

Keywords

Please provide 4 to 6 keywords which can be used for indexing purposes.

Text Formatting

Manuscripts should be submitted in Word.

- The text of a research paper should be divided into Introduction, Materials and Methods, Results, Discussion, Acknowledgements, Conflict of Interest, and References.
- Materials and Methods must include statement of Human and Animal Rights.
- Use a normal, plain font (e.g., 10-point Times Roman) for text.
- Use italics for emphasis.
- Use the automatic page numbering function to number the pages.
- Do not use field functions.
- Use tab stops or other commands for indents, not the space bar.

- Use the table function, not spreadsheets, to make tables.
- Use the equation editor or MathType for equations.
- Save your file in docx format (Word 2007 or higher) or doc format (older Word versions).

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Abbreviations should be defined at first mention and used consistently thereafter.

Footnotes

Footnotes can be used to give additional information, which may include the citation of a reference included in the reference list. They should not consist solely of a reference citation, and they should never include the bibliographic details of a reference. They should also not contain any figures or tables.

Footnotes to the text are numbered consecutively; those to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data). Footnotes to the title or the authors of the article are not given reference symbols.

Always use footnotes instead of endnotes.

Acknowledgments

Acknowledgments of people, grants, funds, etc. should be placed in a separate section before the reference list. The names of funding organizations should be written in full.

Automatic Line Numbering function

You will find both the automatic numbering function for the pages and lines in the main under "function". You need to open the "document" and look for the layout.

References

Citation

Reference citations in the text should be identified by numbers in square brackets. Some examples:

1. Negotiation research spans many disciplines [3].

2. This result was later contradicted by Becker and Seligman [5].

3. This effect has been widely studied [1-3, 7].

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a reference list.

Reference list entries should be alphabetized by the last names of the first author of each work and numbered consecutively.

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Gamelin FX, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L (2009) Effect of high intensity intermittent training on heart rate variability in prepubescent children. Eur J Appl Physiol 105:731-738. doi: 10.1007/s00421-008-0955-8 Ideally, the names of all authors should be provided, but the usage of “et al” in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al (1999) Future of health insurance. N Engl J Med 965:325–329

Article by DOI

Slifka MK, Whitton JL (2000) Clinical implications of dysregulated cytokine production. J Mol Med. Doi:10.1007/s001090000086

Book

South J, Blass B (2001) The future of modern genomics. Blackwell, London

Book chapter

Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257

Online document

Doe J (1999) Title of subordinate document. In: The dictionary of substances and their effects. Royal Society of Chemistry. Available via DIALOG. http://www.rsc.org/dose/title of subordinate document. Accessed 15 Jan 1999

Always use the standard abbreviation of a journal's name according to the ISSN List of Title Word Abbreviations, see

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Tables should always be cited in text in consecutive numerical order.

For each table, please supply a table caption (title) explaining the components of the table.

Identify any previously published material by giving the original source in the form of a reference at the end of the table caption.

Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data) and included beneath the table body.

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For the best quality final product, it is highly recommended that you submit all of your artwork – photographs, line drawings, etc. – in an electronic format. Your art will then be produced to the highest standards with the greatest accuracy to detail. The published work will directly reflect the quality of the artwork provided.

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- Supply all figures electronically.
- Indicate what graphics program was used to create the artwork.

- For vector graphics, the preferred format is EPS; for halftones, please use TIFF format. MSOffice files are also acceptable.
- Vector graphics containing fonts must have the fonts embedded in the files.
- Name your figure files with "Fig" and the figure number, e.g., Fig1.eps.

Line Art

- Definition: Black and white graphic with no shading.
- Do not use faint lines and/or lettering and check that all lines and lettering within the figures are legible at final size.
- All lines should be at least 0.1 mm (0.3 pt) wide.
- Scanned line drawings and line drawings in bitmap format should have a minimum resolution of 1200 dpi.
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If any magnification is used in the photographs, indicate this by using scale bars within the figures themselves.
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Definition: a combination of halftone and line art, e.g., halftones containing line drawing, extensive lettering, color diagrams, etc.
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Variance of type size within an illustration should be minimal, e.g., do not use 8-pt type on an axis and 20-pt type for the axis label.

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APPENDIX C: PHYSICAL THERAPY IN SPORTS

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All manuscripts must comply with the following:

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Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

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Reference to a book:

Magee, D.J. (1997). *Orthopaedic physical assessment.* (3rd ed.). Philadelphia: Saunders.

Reference to a chapter in an edited book:

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APPENDIX D

Journal of Dance Medicine & Science Guidelines for Authors

The *Journal of Dance Medicine & Science* publishes scholarly, scientific articles on all aspects of dance medicine and science and draws from the multidisciplinary fields of anatomy and physiology, biomechanics, general medicine, sports medicine and surgery, physical therapy, dance education, kinesiology, psychology, and nutrition and diet.

Articles may be scholarly or report clinical or basic scientific information or research results. The journal also considers review articles summarizing the body of knowledge available on focused topics in dance medicine and science.

Articles for the journal's consideration should emphasize:

• The identification, treatment, rehabilitation, and prevention of illness and injuries.

• General health, nutrition, and exercise.
• The application of scientific research to dance training.

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Clinical and Basic Science Research articles should include: Abstract, Introduction, Material and Methods, Case History (if applicable), Results, Discussion, Conclusion, and References.

Review articles should provide a comprehensive synthesis of the available information on their chosen topic. They must include headings and reference citations.

Case Reports should be brief reviews of either typical or atypical presentations of diseases and disorders and should include an Abstract, Introduction, Case Report data and findings, Discussion, Conclusion, and References.

All articles should include a short statement preceding the Conclusion that explains the study's relevance to the health, well-being, training, and/or performance of dancers.

Original Research

When reporting original research involving human subjects, authors should state in their Methods section whether the subjects gave informed consent and whether the study was approved by a research ethics committee.

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Each manuscript must include a title page citing: 1. title of the article, 2. names and academic affiliations of all authors, and 3. the corresponding author's mailing address, telephone and facsimile numbers, and e-mail address.

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4. Adams S. Cause and prevention of dance injuries: the sciences behind the art. Runner. 1983;21(3):10-5.

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• Name of Publisher
• Year of Publication
• Inclusive page numbers of the chapter

7. Teitz CC. Knee problems in dancers. *In:* Solomon R, Solomon J, Minton SC (eds): *Preventing Dance Injuries*. Champaign, IL: Human Kinetics Publishers, Inc., 2005, pp. 53-72.

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9. Barham JN, Wooten EP. *Structural Kinesiology.* New York: Macmillan Publishing Company, Inc., 1973.

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