REVIEW OF RESEARCH AND METHODS REGARDING THE DIAGNOSIS OF HIP IMPINGEMENT

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Abstract

One of the main reasons for OA (Osteoarthritis) is hip impingement and surgery regarding this is one of the most common operations performed in sports medicine. The cost of such intervention is hard to evaluate because medical centres assert that details regarding their charges and costs are proprietary information. However, reports from one academic medical centre have indicated the cost of hip impingement surgery is less than that of THR (Total Hip Replacement) (Kolata, 2011) which may suggest that the early detection of FAI(Femoroacetabular Impingement) could reduce the cost burden of this form of surgery for the NHS.

The mean time taken from the initial symptoms emerging to a final diagnosis of FAI is three years (Clohisy, Knaus and Hunt, 2009). Early diagnosis is very challenging since many FAI patients experience an insidious onset of symptoms that is similar to other muscle dysfunction related diseases. Many of them go through delays and incorrect diagnoses as well as treatment recommendations that are ineffective. but late diagnosis causes OA and damage to soft tissue. FAI occurs in young and active adults who need a full range of motion and so detection at an early stage is essential. Moreover, there is a pressing need to investigate a reliable, valid and easy to implement impingement detection framework. In this review paper there is a discussion of methods and research regarding detecting hip impingement along with a consideration of their limitations.

Keywords: Hip Impingement, Detection, FADIR and FABER Test

Introduction

The hip joint is considered an important joint because two thirds of total body weight is carried by it and during daily activities, forces equal to five and a half times body weight are shifted between the femur and pelvis (Hodge, et al., 1986; Bergmann, et al., 2001; Bergmann, et al., 1997). With improved healthcare provision, people are living longer and some medical conditions are becoming more common. One such condition is osteoarthritis and in Wales and England during 2012 more than 160,000 hip replacements were performed (Anon., 2012). The causes for the onset of OA remains debatable but it is widely accepted that femoroacetabular impingement (FAI) plays a substantial role (Ganz, et al., 2003). FAI is a condition arising from abnormal contact between the head of the femur and the acetabulum (Ganz, et al., 2003).

FAI develops among the young particularly when they are active and take up sport. So there is a need to develop an accurate and reliable method to detect the FAI. Approximately 10% to 15% of the adult population are clinically diagnosed with it (Leunig & Ganz, 2005) and most of these are young, active and sporty adults. Moreover, in the population diagnosed with FAI the numbers of males are higher than females.

The development of OA invariably leads to total hip replacement (THR) surgery. However, for younger patients, this may not be the best solution for their hip pain, because it can lead to numerous difficult revisions later in life. As hip impingement usually happens amongst young active adults (Leunig, et al., 2005), early detection and treatment can avoid OA and subsequent THR. As life style choices of people change and particularly younger ones are keen to take up sports, more of the population may encounter hip impingement and thus, over the past few decades, this matter has become the focus of extensive academic interest. Impingement has been studied by many authors (Eijer, et al., 2001), (Ganz, et al., 2003), (Jäger , et al., 2004), (Murphy , et al., 2004), (Siebenrock , et al., 2003), (Strehl & Ganz , 2005), (Leunig, et al., 2009) with some of the literature addressing its assessment and treatment.

I.

1 Femoroacetabular Impingement (FAI)

The condition FAI refers to an abnormal contact between the acetabulum and the head of the femur (Ganz, et al., 2003; Leunig, et al., 2009; Leunig, et al., 2009; Kubiak-Langer, et al., 2007). Ganz et. al (2008) studied the morphology of the hip as one important factor pertaining to the development of FAI and found that it was due to an activation of OA of the hip. When this problem is not treated properly, then young people who are affected with FAI, can have OA problems in the hip later in life. High levels of hip activities and a high ROM (Range of Motion) can speed up the onset of hip FAI and OA. Thus, it follows that the treatment of FAI can decrease the population troubled with hip OA. FAI generally happens in young people with the slow beginnings of a growing level of pain which is initiated just after a trauma. During the initial stages, the groin pain is not regular but may become intensified through undertaking excessive hip related activities such as athletics or intensive walking for long periods (Ganz, et al., 2003; Ganz, et al., 2008; Griffin, 2007).

In general, two types of impingement are defined and each concern the shape of the deformity in the structure of the hip. The types are differentiated on the basis of the impingement mechanism and origins and are termed cam and pincer (Tannast, et al., 2007; Iko, et al., 2001).

2 Detection of Impingement

Detection of the impingement in its early stages can avoid the progression to OA. However, detecting FAI is not an easy procedure and surgeons have misdiagnosed it by confusing it with other hip muscular diseases and so, in practice, it often takes a long time to detect. Clinical examination and radiography examinations have been proposed by various scholars as a means to diagnose FAI accurately (Nussbaumer, et al., 2010; Kuhlman & Domb, 2009).

2.1 Physical or Clinical Examination

The technique of surgical dislocation of the hip has been used for identifying the FAI mechanism (Ganz, et al., 2008). In most cases, the patients complained of anterior groin pain which is then worsened by flexion on the hip (Philippon & Schenker, 2006). Such patients also complain about groin pain that is experienced when sitting for prologued periods or getting in or out of the car. In addition, FAI has been reported as the main reason for hip pain, reduced ROM in athletes and reduced athletic performance. Delayed diagnosis and inaccurate diagnosis are two main problems in FAI diagnosis but early and accurate diagnosis can avoid OA and damage to soft tissue (Clohisy, et al., 2009). However, the mean time from onset of symptoms to final diagnosis has been reported to be as long as three years.

Patients with FAI usually have antero-lateral pain in their hips. More often the patients complain about pain in their antero-lateral hips, indicated with fingers and thumb as a “c” shaped pain area (Byrd, 2007). In addition, they have a sharp pain when turning towards their problematic side. The clinical examination of the hip starts with a full assessment of the problem, palpation and motion range assessment. The stages used to detect hip impingement are as follows. The first stage involves examination of the hips which asymmetry recommends SI (sacroiliac joint) for joint dysfunction or leg-length discrepancy which, in addition, could cause SI joint pain, pubic symphysis pain or muscle pain. The second step requires palpation of the bone landmarks and muscles, for, any tenderness indicates that tissue is involved. Tenderness revealed over the greater trochanter points to trochanteric bursitis, which can coincide with intra-articular hip disorders whilst a mass indicates the presence of a tumor. The next check addresses the range of motion, that is, flexion, extension, abduction, adduction, internal and external rotation. These are used to assess for pain and to localise it. Pain sensed in a stretched muscle indicates strain; pain in the groin suggests an intra-articular hip disorder; pain with slight motion is an indicator for septic arthritis. The next step involves undertaking the FABER test which is short for flexion and abduction, in detail, with 90° flexion and external rotation in 90° flexion. An additional examination can be carried out by using the FADIR test which is shorthand for adduction in 90° and internal rotation in 90°. A number of different physical examination methods are available for detecting FAI. The FADIR test, which requires flexion, adduction in 90° flexion and internal rotation in 90° flexion is the one most commonly used (Byrd, 2007; Byrd & Jones, 2004). This particular test has been adopted in not only clinical examinations but also in testing using a computer aided programme (Kuhlman & Domb, 2009).

Several problems have been identified regarding physical testing and expalained in section 3.1 of this paper. For instance, finding the beginning point of the examination, locating the rotation centre, testing a limb with a longer axis and measuring horizontal as well as vertical positions (Kuhlman & Domb, 2009). Goniometers require both hands to be used thus leaving no free hand with which to stabilize the proximal part of the femoral joints (Lea & Gerhardt, 1995). In addition, goniometers can only be used for assessing the flexibility of joints in terms of two dimensions and other challenges are encountered when monitoring those joints which are enclosed with soft tissue such as the hip.

After a patient is diagnosed as showing symptoms of FAI by using the tests mentioned above under physical and clinical examinations, the individual is asked to undertake an MRI and/or CT (Toomayan, et al., 2006). More specifically, CT and MRI scans are taken of the patient assuming a position of 90° flexion and 20° abductions in the Dunn view[1] (Meyer, et al., 2006). If all the evidence confirms that the patient is diagnosed as having FAI then he/she is sent to have the FAI removed by surgery (Martin, et al., 2008). Clohisy et al. (2009) claimed that FAI patients misdiagnosed as suffering with other hip diseases and delays in the correct diagnosis end up developing OA, so speedy and accurate detection of FAI through clinical examination is important.

The hip with FAI symptoms has average of 97^0 flexion and 9^0 internal rotations in 90° flexion (Clohisy, et al., 2009). These values are lower than the 110^0-120^0 for flexion and 30^0-40^0 for internal rotation in

[1] Antero-posterior view of the hip with the patient supine and with the hips and knees flexed at 90°, the legs abducted 15°- 20° from the midline

flexion reported in normal people (Clohisy, et al., 2009). This is one of the main examination to detect hip impingement.

Philipon et al. (2007) studied a population of patients with hip pain and examined them using the FADIR test. They reported that 50% of the population after undergoing MRI and CT were diagnosed as having FAI. From the resultant 50%, 99% of them had a positive outcome for the FADIR test for FAI diagnosis. Similarly, Ito et al. (2004) revealed that 90% of patients who had a positive FADIR test were diagnosed with FAI. Consequently, these authors claimed that the FADIR test is a reliable and accurate means of detecting FAI.

2.2 Radiographic Parameters Examinations

A sound knowledge of FAI biomechanics can help physicians in designing interventions which reduce the risk of progression to OA. However, future research still needs to focus on two points, specifically, the etiological study of disorders and the nature of the motions of impinging joints which gives rise to the degeneration of tissues. So Early recognision of FAI avoids risk of OA. There are several parameters defined for recognising impingements as shown in figure 1 and table 1.

Table 1: Radiographical parameters used to indicate hip impingement.

Parameter	Definition
CEA (centre edge angle)	The angle between the line sketched from the edge of the acetabulum to the central part of the head of the femur as shown in Figure 1a and vertical lines, as shown in Figure 1a (Marti and Tashman, 2010), (Lever and O'Hara, 2008).
The alpha angle	This angle lies between the axis of the neck of the femur and a line from the central part of the femur head as shown in Figure 1b (Marti and Tashman, 2010), (Lever and O'Hara, 2008).
Femoral head-neck offset	In Figure 1c, line 1 has been drawn with the axis of the neck of the femur. Line 2 has been drawn that is similar to line 1, but lies alongside the margin of the head of the femur. Line 3 has been drawn similar to both lines 1 and 2 but it transects the asphericity point for measuring the alpha angle. The offset of the line head shown as "OS" in Figure 1c and the neck is found as a tangential space between lines 2 and 3. (Hossain and Andrew, 2008).
Acetabular index	The acetabular index in adults is defined as the angle between the horizontal line and tendency of sourcil which refers to that part of sclerosis within the superior view of the acetabulum, as shown in Figure 1d from the supine position (Lever and O'Hara, 2008).

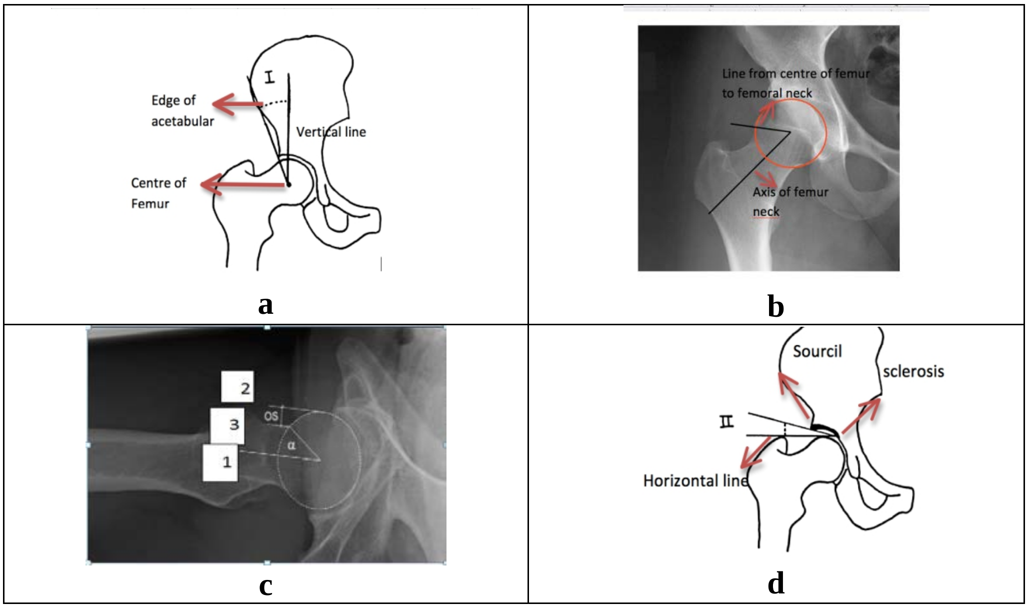

Figure 1: 1a Measurement of the centre edge angle **(Lever and O'Hara, 2008), 1b)** measurement of the alpha angle in the supine position **(Taunton, 2011), 1c)** the alpha angle and normal head-neck offset in the lateral view **(Hossain and Andrew, 2008),** 1d) measurement of adult acetabular index in the supine position (anterior view of hip) **(Lever and O'Hara, 2008)**

Table 2 contains a summary of the radiography parameters which are measures for cases of impingement and for the normal hip (control group individuals). Although use of just one of the listed parameters is sufficient to detect impingement (Ochoa, et al., 2010), some researchers have claimed that the patient position at the time of radiography may create errors in measuring such parameters accurately (Hossain & Andrew, 2008). Ochoa et al. (2010) studied patients who had positive signs of impingement. They discovered that 87% of patients with hip pain were found to have at least one impingement related signs, that is, the α angle, head-neck offset, CEA angle, and/or the acetabular index were not within an acceptable range. Likewise, Kapro et al. (2011) studied 67 male football players who complained about hip pain and reported that 72% of this population had an abnormal alpha angle, and 64% had a decreased head-neck offset.

Table 2: Radiographic parameters used to indicate impingement (Hossain & Andrew, 2008)

Radiographic Parameters	*Control group*	*Impingement group*
α angle	42° to 47°	65° to74°
Head neck offset	11.6±0.7mm	7.2±0.7mm (<8mm for cam impingement)
Acetabular index	30°	Above 35°
CEA angle	40°	Less than normal group

3 Previous Research on FAI

The extant clinical research on this concept specifies that FAI takes place when cam and pincer impingement give rise to early contact. This then causes damage within the substantial labrum and the prearthrotic chondral in active young adults (Ganz, et al., 2003; Eijer, et al., 2001; Jäger, et al., 2004; Murphy, et al., 2004; Siebenrock, et al., 2003; Strehl & Ganz, 2005). Many common daily activities, such as prolonged sitting, squatting, stair climbing, and athletic exertion requiring a large ROM, produce hip pain in people with FAI (Kennedy, et al., 2009; Adams, et al., 1999; Lamontagne, et al., 2009). Early diagnosis is very challenging since many of FAI patients have insidious onset of symptoms which are the same as other muscle dysfunction diseases (Clohisy, et al., 2009). There is a major need to investigate reliable, valid and easy impingement detection framework. 74% of the FAI patients have reported significant reduction in flexion and internal rotation in flexion (Clohisy, et al., 2009), (Jäger , et al., 2004), (Leunig, et al., 2004), (Siebenrock , et al., 2003).

For the purposes of this paper, the previous research on FAI is divided into two: experimental and computational.

3.1 Experimental Research

The goniometer is the simplest and most commonly used clinical device for detecting impingement. The advantages of the goniometer are its simplicity for assessing ROM, direct measurement of joint angles without any data reduction process being required, and the low cost of the instrument. The two-arm goniometer is still the most widely used, economical and portable device for the evaluation of ROM (Lea & Gerhardt, 1995). However, major drawbacks of goniometry are that the starting position, the centre of rotation, the long axis of the limb and the true vertical and horizontal positions can only be visually estimated (Nussbaumer, et al., 2010). Moreover, conventional goniometers must be held with two hands, leaving neither hand free for stabilization of the body or the proximal part of the joint. In addition, manual goniometers assess joint flexibility only in two dimensions but as most of the hip ROM measures assessed in clinical practice are in-plane movements, this limitation is minor. There are also difficulties in monitoring joints that are surrounded by large amounts of soft tissue, such as the hip (Allard, et al., 1994). Also goniometers tend to overestimate the majority of passive hip motion patterns by measuring intersegment angles (e.g. thigh flexion on trunk for hip flexion) rather than true hip ROM and it is suggested that it is difficult to reproduce true hip ROM as this requires placing the goniometer properly and performing the anatomically correct ROM (Nussbaumer, et al., 2010). Several authors reported restrictions in terms of measuring internal rotation and flexion

(Tannast, et al., 2007; Jäger , et al., 2004; Ganz, et al., 2003; Nussbaumer, et al., 2010). Furthermore, substantial errors in clinical measurements can occur if the examiner fails to recognise individual tilt or pelvic rotation (Kubiak-Langer, et al., 2007) as tilt and rotation are difficult to control during an examination and can vary considerably when the patient is in the supine position (Greene & Heckman, 1994;Tannast, et al., 2005).

In light of these problems some researchers have started to use an electromagnetic tracking system (ETS) to measure ROM (Nussbaumer, et al., 2010). Some findings of these studies have reported that goniometric measurements of passive hip motion can provide greater ROM values than those obtained by applying the ETS. The ETS device has several further limitations. First, those relating to instruments, second, errors concerning the anatomical land marks being used and, third, skin movement issues that may cause some further errors. ETS can be used as the standard device for hip ROM assessment. Fluoroscopy and bone-pins would be more accurate to measure ROM of hip, although potential errors are the same.

A Motion Capture laboratory has been used for the purposes of examination of patients with FAI during squatting and walking The results of these indicate that the ROM decreases for cases with hip impingement when compared to normal hip cases (Kennedy, et al., 2009; Lamontagne & Kennedy, 2009). However, there are some limitations inherent to kinematic studies of joints. The causes of these emerge from generic calculations, marker misplacements, and inadequate joint centre determination as well as the impacts of skin or clothing on the measures (Leardini, et al., 2005; Della Croce, et al., 2005; Reinschmidt, et al., 1997). Moreover, under these conditions, gait is not affected but the ROM of the hip may be restricted, particularly regarding the flexion, internal rotation and adduction (Kennedy, et al., 2009). The speed of walking and the ROM observed for a normal walking pace is the same for both cases: the hip with FAI and the hip without.

3.2 Computational Research

Various studies have reported on the ROM preoperatively and postoperatively using a 3D model of the hip (Tannast, et al., 2007; Kubiak-Langer, et al., 2007; Bedi, et al., 2011; Bedi, et al., 2012; Beaulé, et al., 2005). Results of these showed that the ROM can be improved by using computer simulation and arthroscopic osteoplasty (Tannast, et al., 2007; (Kubiak-Langer, et al., 2007; Bedi, et al., 2011; Bedi, et al., 2012). The measurement of only the alpha angle is not sufficient for detecting the benefits of arthroscopy (Bedi, et al., 2011; Bedi, et al., 2012). The identification of impingements and preoperative assessment can assist surgeons in making decisions regarding appropriate operative treatments

(Kubiak-Langer, et al., 2007) and entire dislocation for observing the patho-mechanism is not necessary, as the causes of impingement can be found preoperatively (Lavigne, et al., 2004) by applying commputer assisted techniques. Some invasive approaches like commputer assisted techniques can be used for carrying out surgical procedure of FAI, only if amount of bone to be removed is established preoperatively (Kubiak-Langer, et al., 2007).

Some research reveals that bespoke software can be an effective tool in identifying impingement diseases preoperatively (Kubiak-Langer, et al., 2007; Hu , et al., 2001; Kang , et al., 2002). More specifically, CT based models can assist surgeons with identifying the impingement zone accurately and subsequently apply less invasive methods (Tannast, et al., 2005; Brunner, et al., 2009; Monahan & Shimada, 2008; Pearle, et al., 2009; Rivkin & Liebergall, 2009). For instance, the collision detection algorithms based on CT data can be used to calculate the ROM, establish the volume of resection and offer accurate information on pre and post-operative locations of FAI as well as the impingement angle (Bedi, et al., 2011; Bedi, et al., 2012). It has been found that surgical measures for treating FAI are beneficial to patients and surgeons as hip joint surgical dislocation is not essential for observing the patho-mechanicsm of hip joint diseases (Kubiak-Langer, et al., 2007).

Lesions on impingements and damage in soft tissues reduce ROM and CT based computer models can identify the region of impingement within symptomatic patients. With this information, osteoplasty surgery carried out in the identified regions can enhance the ROM, reduce intermittent collisions and chondral injuries in the FAI zone (Bedi, et al., 2011; Bedi, et al., 2012).

The non-invasive type of assessment is necessary for recommendation of suitable treatments and detecting impingement (Tannast, et al., 2007). The non-invasive assessment of FAI is a medical diagnosis of hip impingement without using physical examination. It is an computational diagnosis of FAI. Reliable and correct simulation is quite important (Tannast, et al., 2007). The computer based analysis is matched with the clinical analysis data on range of motion in impingement (Eijer , et al., 2001), (Jäger , et al., 2004), (Leunig, et al., 2004), (Siebenrock , et al., 2003), (Strehl & Ganz , 2005), (Wettstein & Dienst , 2006). So these computer analysis help the surgons to detect impingement.

FAI decreases internal rotation, adduction and abduction using an “analytical coordinate” system (Kubiak-Langer, et al., 2007). The analytical coordinate approach can form the basis for future methods in which the instruments can facilitate intraoperative implementation of osteoplasty. The technique can be combined with some invasive methods such as arthroscopy of the hip and methods involving small incisions that surgically need no hip dislocation (Kubiak-Langer, et al., 2007).

Tannast et al. (2007) developed a non-invasive 3D assessment of FAI termed "Hip Motion". This computer simulation package detects the impingement angle and zone and also measures the ROM of the hip joint. These researchers used two groups of subjects for the 3D modeling: normal and those with impingement and subsequently validated their computer simulation with cadaver samples. It was found that the bespoke program overestimated the ROM when compared to the cadaver samples. In addition, one of the main limitations of the "Hip Motion" program is that it is not applicable to largely dysplastic hips with a shallow acetabulum where an unambiguous centre of rotation cannot be found. In addition, it cannot be used for hips with advanced OA. This is because joint space narrowing leads to a change in the femoral head centre relative to the acetabulum, resulting in a nonconcentric joint morphology.

Kiubiak Langer et al. (2007) used the "Hip Motion" program to measure the ROM of normal cases and FAI cases, before and after surgery. They reported a significant reduction of flexion, adduction and internal rotation in the hip diagnosed with FAI. Their findings showed that there is 5°- 8° improvement in internal rotation, a 15°- 20° improvement in flexion and 1°- 4° improvement in adduction after a surgical operation. However, it was noted that the impingement zone remained the same. Further, it was claimed that information obtained by using the "Hip Motion" program combined with arthroscopy could replace hip dislocation, which is a major operation.

In another study, Tannast et al. (2008) applied the "Hip Motion" program to find impingement locations for several patients and compared the results with hip dislocation surgery. Their outcomes indicated that the hip impingement zone is the same for cases of FAI hips under both methods: that of computer simulation and hip dislocation surgery.

Chegini et al. (2009) studied the effect of hip morphology on the stress distribution on hip cartilage during daily activities in patients with hip impingement. They used a CAD program to make a 3D model of the hip with a different CE angle and then analysed the stress distribution in FEA. The results found that although higher CE angles cause higher contact peak pressure. the place of peak pressure remains the same for all CE angles. These scholars also reported that stress on hip cartilage is higher when walking than standing and that this stress is higher when seated than walking. The stress levels found when seated is higher because of the need to have higher rotation. In conclusion, they noted that stress and peak pressure on hip cartilage depends on joint geometry, motion and the load.

Bedi et al. (2011; 2012) developed computer-assisted 3D modelling to measure the ROM of the hip. Their computer-assisted model did not have centre of rotation and that small load on head of the femur controls hip rotation. Their findings showed that the ROM was improved in FAI patients after surgery.

Kiubiak Langer et al. (2007) and Bedi et al. (2011; 2012) both developed a computational model to detect hip impingement. However they applied different boundary condition to measure the hip range of motion. Table 3 compares their finding.

Table 3: Range of motion for volunteer with FAI according to the previous founding

	Bedi et al. (2011; 2012)	Kiubiak Langer et al. (2007)
Flexion	107°±11°	105.2°±12.2°
Internal Rotation in 90° flexion	19°±13°	11.1°±6.9°

It follows, therefore, there are many limitations which can be specified for previous studies;

a) Soft tissues were not used in the hip models studied computationally for impingement detection (Hu, et al., 2001; Kang, et al., 2002; Kubiak-Langer, et al., 2007; Bedi, et al., 2011; Bedi, et al., 2012). Soft tissue affects surgical interventions and even post-surgical muscular reconditioning. The impingement has been found as a bone to bone contact.

b) Effects of rotation centres are not validated by these previous researchers and they assume that the rotation centres are fixed and that these are at the centre of the femur (Kubiak-Langer, et al., 2007).

c) Previous researchers do not provide enough information on the measurement technique deployed and the accuracy of current methods are not fully considered (Kennedy, et al., 2009).

Conclusion

Early detection and treatment of FAI can eliminate the risk of the development of OA in people with hip impingement. To date, there is no agreement among researchers on how FAI should be is diagnosed. There is clinical and computational research on detecting hip impingement and recently hip modelling has been developed for this purpose. However there are still some limitations when applying this. Moreover, it has been assumed that FAI concerns bone to bone contact and the impacts of soft tissue are ignored. Therefore, there is a need to examine whether or not soft tissues and the centre of rotation play important roles regarding FAI detection. Establishing a reliable and valid impingement detection method is expected to help surgeons seeking to treat impingement effectively.

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