UNIVERSITY OF TURKU

ROLE OF PELVIC INCIDENCE IN HIP DISORDERS

Thesis

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Abstract

The pelvis is a rotating modulator connecting the spine and lower limbs; it helps the body to maintain a vertical position. Pelvic incidence (PI) is fundamental, constant, and unique for each individual measure defined as the angle between the line perpendicular to the sacral plate at its midpoint, and the line connecting this point to the axis of the femoral heads. It regulates spinal curvature and has consequently become an important factor in spinal surgery. It also determines a person's ability to tilt the pelvis into retroversion, which is needed to help compensate for sagittal spinopelvic malalignment in spinal deformities or ageing. When tilting backward and forward, the pelvis rotates around the femoral heads.

Both spinal and hip disorders are common, and they often coexist. Descriptive imaging is essential when specific disorders of the spine and hip are being diagnosed or treated surgically. Previously performed hip replacement is a common condition among patients with a spinal deformity or other spinal disease. Thus a reliable measurement of spino-pelvic alignment is necessary even when a femoral head has been replaced. In addition, disorders of the hip and spine are sometimes related, and, therefore, understanding the complexity and connections of this spinopelvic unit is a widespread clinical challenge.

The aims of this thesis were 1) to investigate whether pelvic incidence is associated with the wear of hip implants in the studied sample; 2) to determine if the radiographic measurement of spinopelvic parameters after hip replacement overall (and the implant position of metal-on-metal hip implants in particular) is reliable; and 3) to evaluate the previous evidence on the connection between pelvic incidence and hip disorders in general. The study was based on data collected from 101 patients who underwent large-diameter-head, metal-on-metal hip arthroplasty. A systematic review, along with a quantitative analysis of the literature on the topic, was conducted.

In this study, no evidence was found that pelvic incidence is associated with metal wear after metal-on-metal hip replacement. The plain radiograph assessment of the position of the total metal-on-metal acetabular component and the spinopelvic parameters was found to be reliable. Hip replacement did not weaken the interpretation of spinopelvic alignment. In addition, pelvic incidence and hip osteoarthrosis seemed to be unrelated. A possible connection between the low pelvic incidence and femoroacetabular impingement observed in this study should be taken into account when clinical decisions are made in spinal and hip surgery.

Keywords: Pelvic incidence, spinopelvic alignment, hip disorders, metal-on-metal hip replacement

TURUN YLIOPISTO
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Tiivistelmä

Lantio on liikkuva välikappale selkärangan ja alaraajojen välillä ja osallistuu ihmiselle tyypillisen pystyasennon ylläpitämiseen. Lantion kiintokulma on yksilöllinen ja muuttumaton mitta, joka ohjaa selkärangan muotoa. Lantion kiintokulma ohjaa useita selkäkirurgisia ratkaisuja. Rangan muodon lisäksi lantion kiintokulma ratkaisee yksilön kyvyn kiertää lantiota etu-takasuunnassa. Tämä kiertoliike tapahtuu lonkkanivelissä. Sitä tarvitaan pystyssä pysymiseksi ja ihmisen ikääntyessä selän virheasentoon johtavissa tiloissa.

Selän ja lonkan sairaudet ovat väestössä tavallisia ja esiintyvät usein yhtaikaa. Selän sairauksien tarkempi diagnostiikka ja kirurginen hoito edellyttävät riittävän tarkkaa selkä-lantio -linjauksen kuvantamista. On tavallista, että selkäpotilaalla on jo ennestään lonkan tekonivel, ja siksi selkärangan asennon mittaamisen tulee onnistua myös potilailla, joilla lonkkanivel on korvattu tekonivelellä. Varsin usein selkäsairaus ja lonkan sairaus liittyvät suoraan toisiinsa. Kliinisessä työssä tällaisen yhteyden hahmottaminen voi olla vaikeaa.

Tässä tutkimuksessa selvitettiin, onko lantion kiintokulmalla yhteyttä lonkan sairauksiin. Arvioitiin esimerkiksi, voisiko lantion kiintokulma vaikuttaa lonkan asentoa ja liikettä määräävänä mittana myös lonkan tekonivelestä vapautuvaan kulumisjätteeseen. Toisena tutkimuksen tarkoituksena oli arvioida selkä-lantio –linjausta kuvaavien määreiden mittauksen luotettavuutta tekonivelleikatuilla potilailla, ja lonkan metalli-metalli –liukupintaisen tekonivelen kupin asennon mittauksen toistettavuutta tavanomaisesta röntgenkuvasta. Tutkimus perustuu 101 tekonivelpotilaan aineistoon, sekä systemaattiseen kirjallisuuskatsaukseen ja siitä tehtyyn analyysiin.

Lantion kiintokulman ja metalli-metalli-liukupintaisen lonkan tekonivelen kulumismuuttujilla ei havaittu olevan yhteyttä, ei myöskään lantion kiintokulman ja lonkan nivelrikon välillä. Havaittiin, että pienen kiintokulman ja ahdas lonkka –oireyhtymän välillä saattaa olla yhteys. Yhteyden tunnistaminen voi jatkossa vaikuttaa myös kliiniseen päätöksentekoon lonkka- ja selkäkirurgiassa. Osoittautui, että lonkan metalli-metalli –liukupintaisen tekonivelen kupin asennon mittaaminen röntgenkuvasta on tarkasti toistettavissa. Selkä-lantio –linjauksen määreiden mittaaminen osoittautui luotettavaksi myös potilailla, joilla oman lonkkanivelen tilalla oli tekonivel. Lonkan tekonivelen ei siten voida katsoa heikentävän selkä-lantio-linjauksen arvioimista röntgenkuvista.

Avainsanat: Lantion kiintokulma, selkä-lantio -linjaus, lonkan sairaudet, metalli-metalli-tekonivel

Table of Contents

Abbreviations

AS	Ankylosing spondylitis
CI	Confidence interval
Co	Cobalt
Cr	Chromium
DDH	Developmental dysplasia of the hip
FAI	Femoroacetabular impingement
FAR	Finnish Arthroplasty Register
ICC	Intra-class correlation coefficient
IQR	Interquartile range
LA	Limits of agreement
LL	Lumbar lordosis
MoM	Metal-on-metal
OA	Osteoarthrosis
PI	Pelvic incidence
PT	Pelvic tilt
SD	Standard deviation
SIF	Subchondral insufficiency fracture
SVA	Sagittal vertebra axis
SS	Sacral slope
THA	Total hip arthroplasty

List of Original Publications

This thesis is based on the following papers, which will be referred in the text by their Roman numerals

I Pernaa K, Seppänen M, Mäkelä K, Saltychev M. Reliability of Sagittal Spinopelvic Alignment Measurements after Total Hip Arthroplasty. Clinical Spine Surgery 2017; 30(7):E909–14

II Saltychev M, Pernaa K, Seppänen M, Mäkelä K, Laimi K. Pelvic incidence and hip disorders. Acta Orthop 2018;89(1):66–70.

III Pernaa K, Saltychev M, Mäkelä K. Relationship between Pelvic Angle and Blood Concentration of Chromium and Cobalt Ions after Metal-on-Metal Hip Replacement: a Brief Report. Scandinavian Journal of Surgery 2018;107(1):91–4.

IV Pernaa K, Saltychev M, Keemu H, Mäkelä K. Measuring acetabular cup orientation after large-diameter metal-on-metal total hip replacement. Submitted.

1. Introduction

Low back pain and ischial pain are common symptoms that rarely require radiological imaging. However, before specific disorders of the spine or hip can be diagnosed and surgically treated, an accurate and descriptive imaging of both the nerve tissue and skeleton is essential.

In the assessment of spinal alignment and the consideration of operative treatment for a degenerative spine, a standing lateral radiograph is the golden standard. The standing image shows the morphology and alignment of the spine in a state of load in an erect position, during which spinal symptoms usually appear. Imaging of higher technology, such as computer tomography and magnetic resonance imaging, are required for diagnostic imaging of, for example, disc pathology, nerve compressions and tumors, but they do not replace the image of a loaded posture.

In the assessment of the degree of malposition of the spine, the Cobb angle measurement has been used for decades. The Cobb angle (Cobb 1948) measures the degree of the most tilted vertebras in the coronal plane in coronal Cobb measurement radiographs. Adult scoliosis is defined as a coronal Cobb measurement of >10 degrees. The common forms include adult idiopathic scoliosis and de novo adult degenerative scoliosis (York and Kim 2017). The prevalence of degenerative scoliosis increases with age and has been reported to be 8.85% for patients over 40 years of age (Kebaish et al. 2011) and even 68% for a healthy adult population with an increasing prevalence with age (Schwab et al. 2005).

Such spinal coronal parameters as the Cobb angle do not take into consideration the three-dimensional aspect of the spine, and they actually have no significant correlation with quality of life or clinical outcome measures (Schwab et al. 2006, Lafage et al. 2009). Instead, spinal sagittal malalignment increases disability (Lafage et al. 2009), and pelvic retroversion of >20 degrees can be considered a sign of malalignment.

In 1998, Jean Legaye and Duval-Beaupère (1998) proposed a fundamental pelvic parameter, the pelvic incidence (PI), which regulates the spinal curvature. Since then, the assessment of spinopelvic alignment and sagittal measures have become increasingly important in determining the treatment and prognosis of structural and degenerative spinal deformities (Mac-Thiong et al. 2004, Barrey et al. 2007, Chaleat-Valayer et al. 2011, Wang et al. 2014). The ideal correction of spinal deformities and the restoration of unique lumbar lordosis (LL) are based on individual pelvic anatomy (Bae et al. 2012).

In addition the prevalence of symptomatic hip osteoarthrosis (OA) increases during ageing (Heliovaara et al. 1993) and reaches 20% in the aged population (Arokoski et al. 2007). Sometimes OA have predisposing anatomical features (Yrjonen 1992, Jacobsen and Sonne-Holm 2005). Inevitably, there is somewhat overlapping with patients suffering from a spinal deformity or hip disorders. The pelvis is a rotating modulator that connects the spine and lower limbs and helps a person to maintain an erect position without falling (Legaye et al. 1998). While rotating forward and backward, the pelvis rotates around the femoral heads. Previous studies have shown that acetabular inclination and anteversion depend on the position and tilt of the pelvis (Siebenrock et al. 2003, Zilber et al. 2004, Aubry et al. 2005). It is possible that a given pelvic morphology and the alignment of the spinopelvic unit may independently affect the development and treatment possibilities of specific disorders of the hip joint. There are differences in pelvis positioning between healthy and osteoarthritic hips (Bendaya et al. 2015), but it is not clear whether they follow degenerative changes over time or depend on individual anatomy.

It has been suggested that spinopelvic measures may be of help also when decisions are made about hip surgery (Hellman et al. 2013, Radcliff et al. 2014). They may affect the planning and performance of a hip replacement, as well as play a role in predicting the outcome of surgery. Philippo and colleagues (2009) suggested that the positioning of the acetabular component of a total hip arthroplasty (THA) should be adjusted to the variations of the spinopelvic unit. For example, patients with spinopelvic malalignment have an increased pelvic tilt (PT) and a high prevalence of excessively anteverted acetabular components of THA (Buckland et al. 2015, DelSole et al. 2016). The correction of a spinal deformity with the use of extensive techniques like osteotomies results in a significant change in the position of the THA acetabular component in the sagittal plane (Buckland et al. 2015, Barry et al. 2017).

Hip replacement is common among patients examined for spinal deformity or disease, and it is necessary that the measurement of spino-pelvic alignment is reliable even if the femoral head has been replaced by arthroplasty. THAs with metal-on-metal (MoM) surfaces were widely used in the past few years, but they were abandoned because of problems – particularly adverse soft tissue reactions - associated with the metal wear of the components. The amount of metal wear, measured in the form of chromium (Cr) and cobalt (Co) ions, can be determined from the blood and used as an indicator of a hip implant's wear (De Smet et al. 2008, Sidaginamale et al. 2013). In addition to ions, radiological imaging is used in the screening and assessment of complications connected with MoM THAs. Radiological imaging of a MoM THA can be challenging (Hart et al. 2009), as metal appears as one bloc in the X-ray, and distinguishing the interface between the components (femoral head, taper adapter and cup) is difficult.

The aim of this thesis was to systematically analyze the relationship between pelvic incidence (PI) and hip disorders. Another objective was to investigate whether PI is such a determining modifier of the pelvic and acetabular position and movement that the degree of PI reflects the wear rates of hip arthroplasty. One objective was to evaluate the reliability of measuring spinopelvic parameters among patients with hip arthroplasty, as well as the reliability of measuring the MoM THA position in radiographs.

2. Review of the literature

2.1. Spinopelvic organization

2.1.1. Pelvic Incidence

Pelvic incidence (PI) is an anatomical measure that is unique to each individual. It was first proposed for use by the French Ginette Duval-Beaupère and Belgian Jean Legaye (1998). While the connection between pelvic orientation and sagittal spinal balance had been recognized earlier (Duval-Beaupère et al. 1992)///// , Duval-Beaupère and Legaye proposed PI as the key factor in this regulation. They defined it as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the center of the axis of the femoral heads (Figure 1). In measuring PI, both X-ray and a new low-dose imaging system called EOS (EOS imaging, Paris, France) has been found to be reliable (Lazennec et al. 2011).

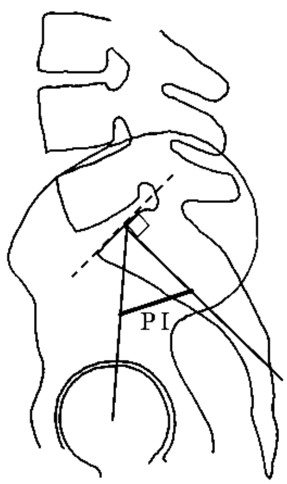


Figure 1a. Low pelvic incidence (PI).

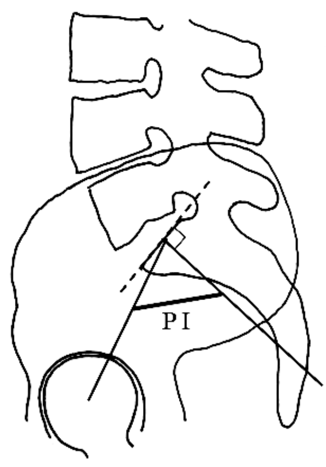


Figure 1b. High pelvic incidence (PI).

PI stabilizes around 10 years of age (Mangione et al. 1997) and varies widely from 33 to 85 degrees (Vaz et al. 2002). Reports on the average PI vary, being estimated to average 51.7 for healthy adults (Vaz et al. 2002), but normative values for PI do not exist, as the variability is comparatively high even for normal subjects (Vrtovec et al. 2012). There is also variation between ethnic backgrounds; for example, the Chinese have been found to have significantly lower PIs than Caucasians (Zhu et al. 2014). PI is considered to be constant and independent of the position of the pelvis. In addition the mobility of the sacroiliac joint is considered to be negligible (Legaye et al. 1998). The PI of adults can be altered only operatively by a posterior sacral subtraction or an anterior addition osteotomy (Bodin & Roussouly 2015), which may be required in cases of extensive lumbar kyphotic deformities when the individual PI is excessive. Theoretically, a sacral fracture, and following a union in malposition, may also alter the PI.

When tilting forward and backward, the pelvis rotates around the femoral heads. The larger the PI, the wider the amount of backward pelvic rotation is theoretically available (Roussouly & Pinheiro-Franco 2011), and, consequently, PI affects the capacity of the rotation of the pelvis around the femoral heads (Barrey et al. 2013).

In spinal surgery, PI is the measure that defines the original sagittal shape of the spine in the case of a developed deformity since PI is associated with the original LL (Legaye et al. 1998). There are indications of a predisposition towards a low or high PI in specific spinal disorders as well (Aono et al. 2010, Chaleat-Valayer et al. 2011, Jentzsch et al. 2013).

2.1.2. Pelvic tilt, sacral slope and lumbar lordosis

Legaye and coworkers (1998) defined pelvic tilt (PT) as the angle between the line connecting the midpoint of the sacral plate to the femoral head axis and the vertical line. Sacral slope (SS) was defined as the angle between the superior plate of S1 and a horizontal line. These two measures reflect the sagittal orientation of the pelvis. A vertical sacral endplate leads to high SS value, while a horizontal sacral endplate leads to low SS value. PT and SS complement each other, and their sum reveals the PI (pelvic incidence = pelvic tilt + sacral slope) (Figure 2).

When a person is in a sitting position, the pelvic tilt is an average of 22 degrees higher than when he or she is in a standing position. The sacral slope varies in reverse order and decreases from the standing to the sitting position (Philippot et al. 2009). A similar change in these measures has been observed also after THA (Ochi et al. 2016). Lumbosacral fusion reduces pelvic motion and renders pelvic tilting impossible (Lazennec et al. 2013).

THA has not been found to change the amount of PT (Blondel et al. 2009, Masquefa et al. 2015). Theoretically, the THA of a restricted hip should allow more hip

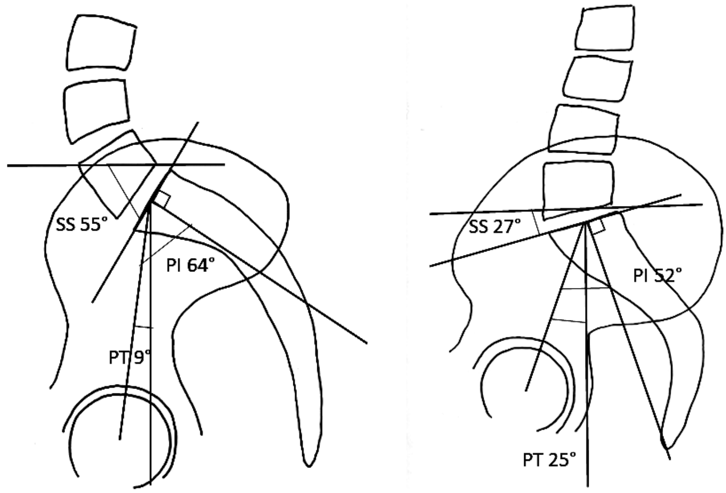


Figure 2. Pelvic incidence (PI) = pelvic tilt (PT) + sacral slope (SS).

extension and pelvic retroversion. This phenomenon has been reported only for patients with ankylosing spondylitis (Gao et al. 2015). However, increasing lumbar lordosis by 30 degrees with the use of spinal osteotomies after THA decreases the PT (Buckland et al. 2015).

Lumbar lordosis (LL) refers to the curvature of the spine, starting from the end-plate of S1 and ending at the point of inflection between the lumbar and thoracic curvatures (Roussouly et al. 2003). The length of LL varies greatly, the proximal limit being higher or lower than the anatomical limit between the lowest thoracic and uppermost lumbar vertebras (Roussouly & Pinheiro-Franco 2011). However, in most cases, major part of LL occurs between the L4–L5 and S1 vertebras (Roussouly et al. 2005) (Figure 3).

Lumbar lordosis is not found in other species, and the curves of the human spine allow humans to be in a perpetually erect position (Roussouly & Pinheiro-Franco 2011).

Legaye and coworkers (1998) originally observed that a low PI is associated with low LL. Later, the connection between PI and LL was demonstrated in several studies, and some mathematic relationships have been proposed (Legaye & Duval-Beaupère 2005, Le Huec & Hasegawa 2016). Schwab and coworkers (2009) have provided a widely used estimation (LL = PI ± 9°). Estimating the adequate lordosis utilizing these estimations is an everyday routine for spine surgeons.

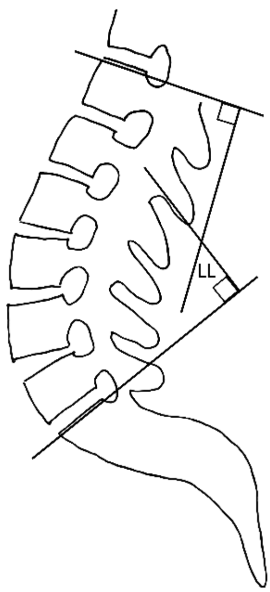


Figure 3. Lumbar lordosis.

Figure 4a. Normal sagittal vertebra axis (SVA) 0 mm.

Figure 4b. Positive sagittal vertebra axis (SVA).

2.1.3. Spinopelvic balance

Human bipedalism indisputably involves many advantages, but the ability to stay upright while economically running, carrying, or standing also requires a smooth interaction of the whole musculoskeletal system. The pelvis is the point where mobile lower limbs join the spine, therefore supporting the trunk.

Global spinal balance is achieved as a result of an optimal lordotic positioning of the spine above a correctly oriented pelvis (Legaye et al. 1998). The shape of the spine is oriented by the PI (Roussouly & Pinheiro-Franco 2011). The balance can be considered to be like that of an open chair, where the shape and orientation of each segment that links the head to the pelvis are related (Berthonnaud et al. 2005). The PI is the only fixed spinopelvic parameter, and SS, PT and LL can be converted to maintain the body's balance. Furthermore, in cases of spinal deformity, a constant PI is the only signature which determines the original shape of the spine (Roussouly & Pinheiro-Franco 2011).

The sagittal vertebral axis (SVA) is the distance of a plumb line drawn from the middle of the body of C7 and the posterosuperior corner of S1 (figures 4a and 4b). For adults, the mean SVA is 0.5 cm (SD±2.5 cm), and an offset greater than 2.5 cm is considered out of the normal range (Jackson & McManus 1994). Adolescents, however, tend to stand in a more negative sagittal balance (Vedantam et al. 1998). With ageing, the spine inclines anteriorly, and the SVA increases. Simultaneously, a posterior pelvic shift in relation to the feet is observed (Schwab et al. 2006). The pelvis permits the maintenance of the gravity line, as the pelvis can be used as a regulator of balance because of its potential to vary tilt and anteroposterior translation (Lafage et al. 2008). Theoretically, the maximum value of PT is equal to PI, and the personal ability to turn the pelvis to retroversion (increasing the PT) is limited by the PI.

Sagittal malalignment causes pain and dysfunction (Glassman et al. 2005). Lafage et al. (2009) demonstrated that a high positive SVA correlates with increasing disability, as measured by the spine-related Oswestry Disability Index. To compensate for sagittal malalignment, patients develop several mechanisms, such as hip extension, knee flexion, and increasing PT (Lazennec et al. 2013). High PT values express compensatory pelvis retroversion for sagittal malalignment (Lafage et al. 2009).

Eyvazov and coworkers (2016) did not note a significant change in sagittal balance after the performance of THA, whereas Weng et al. (2016) reported improvement in global sagittal balance. The effect of a THA on global sagittal alignment is controversial, although Ochi and coworkers (2017) recently suggested that balance may improve after THA in cases when the pelvis is preoperatively in anteversion, as this state indicates a residual compensatory ability.

2.1.4. Acetabular orientation

The acetabulum is a concave cavity of pelvis that forms the hip joint together with the femoral head. The orientation of the acetabulum can be described in numerous planes in anatomical, radiological and operative assessments (Murray 1993).

Anatomic anteversion is referred as the angle between the transverse axis and the acetabular axis in the transverse plane. Radiographic or planar anteversion is referred as the angle between the coronal plane and the acetabular axis (Murray 1993). Assessment of radiographic anteversion is significantly affected by positioning of the patient and pelvic tilt (Tannast et al. 2005, Haenle et al. 2007), and several

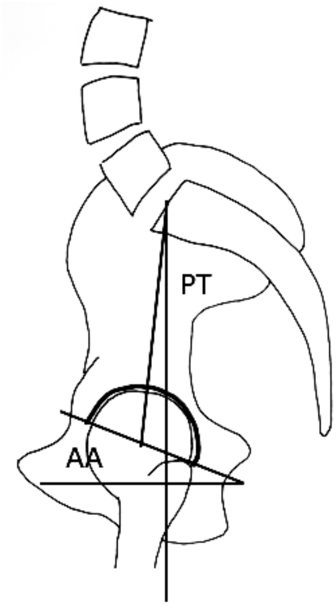


Figure 5a. Pelvic tilt (PT) and acetabular anteversion (AA) in standing position.

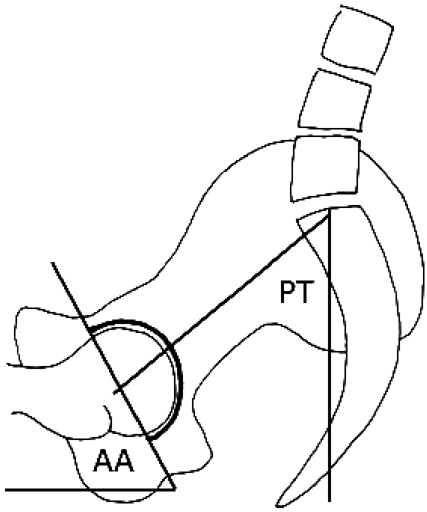


Figure 5b. Pelvic tilt (PT) and acetabular anteversion (AA) in sitting position.

two- and three-dimensional methods to assess the true anteversion have been presented (Nunley et al. 2011, Barbier et al. 2014, Jóźwiak et al. 2015). Radiographic inclination is referred as the angle between the acetabular axis, which is projected to coronal plane, and longitudinal axis (Lewinnek et al. 1978). Posture of the patient affects also to the assessment of inclination; leg length discrepancy and pelvic obliquity are associated with changes in inclination (Tiberi et al. 2015).

The acetabulum in asymptomatic population is anteverted around twenty degrees (Hildebrand et al. 2012). Traditionally, to avoid dislocations of THA, safe zone for acetabular component positioning has been reported to be 5°-25° for anteversion and 30°-50° for inclination (Lewinnek et al. 1978). However, physiological pelvic tilt varies between patients and by patient position (Figure 5), and tilting of pelvis simultaneously increases or decreases the acetabular anteversion (Henebry and Gaskill 2013). From standing to sitting, sacrum tilts posteriorly while acetabulum anteverts (Lum et al. 2018).

Patients who are unbalanced in a spinopelvic point of view, have an increased PT and consequently an increased acetabular anteversion. Rigid patients, for example patients with ancylosing spondylitis (AS) or prior lumbosacral fusion, lack the ability to compensate with PT, and acetabular anteversion will not increase even when sitting (Phan et al. 2015). Due to the risk for impingement and dislocation associated with these conditions, Stefl and coworkers (2017) have recently proposed a recommendation for customizing acetabular component of THA according to the patient´s capability to spinopelvic motion.

2.2. Hip–spine syndrome

The prevalence of low back pain approaches 35%–40 % in the Finnish population, and the prevalence of symptomatic hip OA increases with age and reaches 20% in an aged population (Arokoski et al. 2007). Most disorders related to the spine and hip OA are part of the same degenerative process of man, and they often coexist. Sometimes spinal and hip disorders are related. Although orthopedic surgeons are educated to direct management at the primary pain generator, finding the proper offender may sometimes be complicated with the so-called hip–spine syndrome (Devin et al. 2012).

The relation between hip and spine disorders was first recognized by Offierski & MacNab (1983). They rated the syndrome "simple" when the pain referred to one or the other (hip or spine) location and "complex" when the pathology referred to both locations. The hip–spine syndrome was rated "secondary" in cases in which hip OA resulted in a fixed deformity followed by lumbar malposition. The description of the syndrome was based on the improvement of low back pain after treatment for hip OA. Later on, several reports on the facilitation of low back pain symptoms after total hip replacement have been published (Ben-Galim et al. 2007, Eyvazov et al. 2016).

It has been estimated that 25%–100% of the patients who undergo total hip arthroplasty (THA) for hip arthrosis have reported low back pain (Ben-Galim et al. 2007, Parvizi et al. 2010, Hsieh et al. 2012). After surgical intervention with THA, low back pain quiets down in as many as two-thirds of the patients, including also patients with a known spinal disorder (Parvizi et al. 2010, Chimenti et al. 2016). The reverse process is also possible in that one-tenth of all patients without prior low back pain may develop it after total hip replacement. For half of these patients the pain can be connected to a previously unrecognized spinal disorder. One explanation may be the improved walking ability, which leads to pronounced claudication symptoms (Parvizi et al. 2010).

Not only the elderly or patients suffering degenerative hip disorders have overlapping hip and spine symptoms. Also in younger patient cohorts of symptomatic femoroacetabular impingement (FAI), pain in the low back or buttocks is relatively common (Clohisy et al. 2009).

An understanding of the precise mechanisms related to hip and spinal disorders is lacking. Dynamic changes in the PT influence the orientation of the acetabulum – anterior tilt decreases and posterior tilt increases the acetabular version (Ross et al. 2014). Legaye (2009) recommended that attention should be paid to altered acetabular orientation as a result of pelvic malrotation in spinal disorders when performing total hip replacement. A malpositioned acetabulum component may lead to an increased risk of complications, such as dislocations. Lazennec and coworkers (2011) stated that the adaptation to the imbalance induced by disorders of the lower limbs or spine is individual and requires a comprehensive interpretation of the entire complex comprising the spine, pelvis, and femur. Patients undergoing THA after long spinal fusion are at an increased risk of later prosthetic-related complications, - dislocations, mechanical loosening, periprosthetic fracture, and infection - and the interaction of thespinopelvic unit and hip joints offers a practical explanation (Sing et al. 2016). Sing and coworkers (2016) analyzed a database of more than 800 000 patients with THA and found that 2% of the patients had undergone a previous spinal fusion. The risk of dislocations after THA may be increased if the PT is high, as a PT of >20 degrees may predispose a person to anterior dislocation (Sato et al. 2013). Furthermore, patients with pre- and postoperative spinopelvic imbalance have poorer clinical outcomes, as measured with the Harris Hip Score after THA, than balanced patients do (Ochi et al. 2017).

2.3. Spinopelvic complex and hip disorders

Primary hip OA is a disease of the articulation, modified by several factors related to age, genetics and gender. Both aberrant cartilage or loading might generate a series of biological and inflammatory events conducting in thinning and damage of the articular cartilage (Arokoski & Kiviranta 2012). By contrast, secondary OA occurs by a specific etiology (Dzaja & Syed 2015). It has been suggested that a higher PI may contribute to the development of hip OA, as individuals with an increased PI tend to lose the anterior covering of the acetabulum due to excessive PT with ageing (Yoshimoto et al. 2005). It has also been suggested that PI could be a predictive factor for acetabular orientation. Boulay and coworkers (2014) discovered acetabular asymmetry (pronounced inclination and anteversion) on the left side when the PI was small and on the right side when the PI was large.

Gebhart and coworkers (2016) noted a significant correlation between an increased PI and the presence of hip OA when examining cadaver hips. The opposite observation was made by Raphael and coworkers (2016) on the basis of only radiological findings of OA in computer tomography. Weng and coworkers (2016) found no difference in the sagittal morphology of the pelvis for patients with severe hip OA when compared with asymptomatic controls, although the primary and secondary OA patients were not separated. Yoshimoto and coworkers (2005) suggested that a higher PI among young people may contribute to the development of OA, as they found higher PIs for OA patients than for patients with low back pain. Later, Chaléat-Valayer and coworkers (2011) reported lower PIs for patients with low back pain, and, therefore, it is possible that patients with low back pain as a control group formed a misleading reference group to start with.

Developmental dysplasia of hip (DDH) is a prevalent developmental hip disorder, which represents a variety of hip abnormalities from minor insufficient acetabular coverage (dysplasia) to total dislocation of the hip joint (Alsaleem et al. 2015). DDH is significantly associated with radiological development of hip OA (Jacobsen & Sonne-Holm 2005), and is an important etiological factor of premature OA resulting in total hip replacement (Engesæter et al. 2011). Variation in acetabular morphology of DDH is wide. The diameter of the native acetabulum is often small, and bony architecture can be deficient (Greber et al. 2017). Furthermore, acetabular anteversion have been associated with DDH (Yang et al. 2017). Tiziani and coworkers (2015) noticed a connection between acetabular retroversion and low value of PI. On the contrary, no significant correlations linking PI to the acetabular orientation was found in the recent radiological analysis of Sautet and coworkers (2018).

Femoroacetabular impingement (FAI) is a disorder characterized by an abnormal morphology of either the proximal femur or the acetabulum or both, leading to an abnormal contact of the hip joint during motion (Ito et al. 2001, Ganz et al. 2003). In cam-FAI an abnormal femoral head with an increasing radius is squeezed under the acetabulum rim during motion (Ito et al. 2001), whereas pincer-FAI is a result of a linear impact of the acetabulum rim against the head–neck junction in over coverage of the acetabulum (Ganz et al. 2003, Ganz et al. 2008) (Figure 6). Most FAI hips show a mixed pattern (Ganz et al. 2008). All of the represented forms of FAI can cause damage to cartilage or the labrum, leading to secondary hip OA (Beck et al. 2005).

There are few reports on low PIs for FAI patients. It has been suggested that a diminished PT, in individuals with a low PI, may result in over-coverage of the acetabulum and lead to the development of impingement (Gebhart et al. 2014). Morris and coworkers (2016) evaluated cadavers with a very low PI (<35 degrees) and identified cam-FAI morphology in 47% of the examined hips. Comparing different subtypes of FAI, Weinberg and coworkers (2016) suggested that a decreased PI may be followed by a mixed-type of FAI. Pierannunzii (2017) concluded that patents with pincer and combined FAI have a significantly lower PI than pure cam-FAI and healthy controls. They

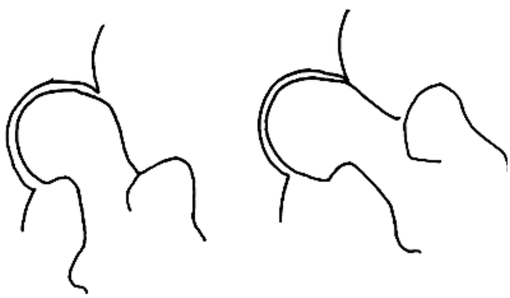


Figure 6a. Cam-femoroacetabular impingement (FAI).

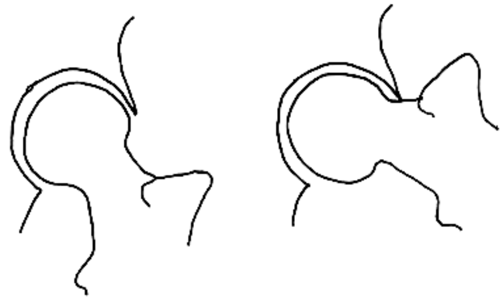


Figure 6b. Pincer-femoroacetabular impingement (FAI).

suggested that the low PI, as an anatomical feature, reduces the maximum PT available, and may consequently enhance the femoroacetabular engagement in dynamic conditions. They also stated that the sagittal pelvic range of movement is a remarkable determinant of whether a cam-FAI hip will be symptomatic or not.

Ankylosing spondylitis (AS) is an inflammatory disease that usually affects sacroiliac joints, the spine and the hips. Typically, LL disappears, and the hips tend to fuse. Especially AS patients with severe spinopelvic malalignment have a potential risk for THA dislocation (Tang & Chiu 2000). Since a decrease in LL leads to an increase in PT and an increase in acetabular anteversion in AS patients (Hu et al. 2016), predisposing them to dislocations of THA, Zheng and coworkers (2014) have recommended that the spinal deformity be corrected prior to THA to aid the positioning of the acetabular component. In addition, Hu and coworkers (2016) found osteotomies to be an effective way of achieving a normal acetabular anteversion in AS patients. On the other hand, Gao and coworkers (2015) have reported an improved sagittal balance after THA in AS patients without spinal osteotomies. In addition, much can be surgically done, besides spinal osteotomy, to avoid THA dislocations, for example, in relation to the selection of the implant, the approach and the navigation.

2.4. Total hip arthroplasty

Several factors can result in symptomatic secondary osteoarthrosis; for example osteonecrosis of femoral head, DDH, fractures, and posttraumatic conditions, in addition to primary OA (FAR). In cases of severe hip OA, total hip arthroplasty (THA) is the treatment of choice (Learmonth et al. 2007). Cemented THA with metal-on-polyethylene bearing surfaces has been considered as a prototype of modern THA (Charnley 1960). Later, cementless THAs, attaching to bone by ossifying, were standardized to the treatment of younger patients because of lasting fixation.

Majority of patients with THA do well. However, some patients with THA require revision surgery later (FAR). In 2017, the most common reasons for a revision operation were infection, dislocation, periprosthetic fracture, the loosening of the implant, and adverse reaction to metal debris (FAR). Revision surgery of THAs is both expensive and predisposed to complications, and the outcome for the patient is seldom as good as after the primary procedure. For a common surgical procedure like THA, it is crucial that the implants used be of the highest possible quality in order to avoid unnecessary revisions.

Osteolysis of the pelvic and trochanteric bone and aseptic loosening of the implant were the classical problems when traditional metal-on-polyethylene bearings were used in primary THA. Alternative bearing surfaces, like ceramic-on-polyethylene, ceramic-on-ceramic, and metal-on-metal (MoM), to avoid wear and osteolysis have been developed.

2.4.1. Metal-on-metal total hip replacements

The first generation of metal-on-metal (MoM) hips (Schmalzried et al. 1996) failed in the 1960's and 70's mainly because of aseptic loosening. These failures were associated with a poor manufacturing process. The next generation of MoM bearings appeared in the 1980's. They were more spherical, and their surface finishing had been improved (Mokka 2015), but their head size continued to be small (28 mm). The main problems were still loosening and dislocation, and survivorship was, at best, equal that of metal-on-polyethylene THA (Dumbleton & Manley 2005).

The aim of the third MoM generation was to preserve femoral bone, and THAs with larger heads and thinner acetabular components were produced when hip resurfacing arthroplasty was introduced in the 1990's (McMinn et al. 1996), eliminating the distinct liner between the metal surfaces of the components. The potential benefits of a large-head, MoM hip arthroplasty were a reduced risk of dislocation and decreased wear of the bearing surfaces (Cuckler et al. 2004). For these reasons, in addition to better functioning, hip resurfacing arthroplasty and large-diameter-head MoM THA became extremely popular worldwide in the beginning of the 2000´s. In Finland, more than 20,000 MoM hip replacements have been performed (FAR).

In any THA, it is advisable that the positioning of the acetabular component follow anatomical parameters. Standards for cup positioning have been described in several reports (Lewinnek et al. 1978, Seki et al. 1998). Optimal placement is significant for a decent clinical outcome, stability, and a sufficient range of movement without impingement (Lewinnek et al. 1978, Kennedy et al. 1998, Kummer et al. 1999). It has been found that suboptimal positioning – insufficient or excessive anteversion or too steep inclination of the acetabular component - may also contribute to the wear rates of MoM bearings (De Haan et al. 2008, Angadji et al. 2009). Concentrations of chromium (Cr) and cobalt (Co) ions released from MoM implants have been found to be related to the position of the acetabular component (Langton et al. 2008). Excess anteversion or retroversion of acetabular component predisposes to edge-loading – the contact between the femoral and acetabular components at the edge of the acetabular component – and is associated with MoM-related pseudotumours (Mellon et al. 2015). Metal wear is not only pertinent with respect to the inside of the hip joint capsule, because ion levels also increase in serum, blood and internal organs (Hartmann et al. 2013).

Between 2005 and 2012 a large-diameter-head MoM THA was the most commonly used THA in the Turku University Hospital, with over 1000 implants being made. Approximately one million large-diameter-head MoM THAs have been implanted worldwide (Lombardi et al. 2012). From the outset, there were worries about carcinogenicity and mutagenicity from exposure to Cr and Co ions (Dumbleton & Manley 2005). Gradually more evidence of intra- and periarticular MoM-bearing-related complications appeared (Pandit et al. 2008). Typically these soft-tissue wear reactions resulted in pain, swelling and pseudotumors around the hip (Macpherson &

Figure 7. Metal-on metal (MoM) total hip arthroplasty.

Breusch 2011). These local findings around the hip were called an adverse reaction to metal debris. It was thought that these tissue reactions were mainly caused by direct cell toxicity from exposure to Cr and Co ions. The reported failure and revision rates were high, 15%–39% (Long et al. 2010, Bosker et al. 2012, Reito et al. 2013), and the use of MoM-THAs was abandoned (MHRA 2012, SAY 2012).

Currently, there are many patients predisposed to potential problems caused by their MoM THA, and, of necessity, they require systematic screening. Therefore, the monitoring of patients with MoM THA will continue for long time (Lombardi et al. 2015). Clinical symptoms, blood ion content and imaging findings are screened. One of the essential components of the evaluation in the follow-up of MoM patients is a routine radiograph to detect osteolysis and loosening (Lombardi et al. 2012). Magnetic resonance imaging is commonly used to detect soft tissue destruction and pseudotumors. For detecting pseudotumors. also ultrasound has been found to have good sensitivity (Lainiala et al. 2015). Radiological imaging of a modular metallic implant may be challenging (Hart et al. 2009), as metal appears as one block in radiographs, and distinguishing the interface between the components (femoral head, taper adapter and cup) is difficult (Figure 7). Accuracy of measuring the position of components in radiological images can also vary between the different models of MoM THAs. In consequence of the supposition that wear of the THA is associated to the position and motion, and also that the amount of the wear (ions released) can be measured, MoM THAs were chosen to be studied in this thesis.

3. Aims of the present study

1. To investigate whether pelvic incidence (PI) is associated with the wear of hip implants in the studied sample (III),

2. To evaluate the reliability of the radiographic measurement of spinopelvic parameters and implant position after metal-on-metal (MoM) hip arthroplasty (I and IV), and

3. To evaluate the previous evidence on the connection between pelvic incidence (PI) and hip disorders in general (II)

4. Patients and methods

4.1. Patients

For studies I, III and IV, data were collected on 101 patients who underwent large-diameter-head, MoM resurfacing (3 patients) or THA (98 patients) in the Turku University Hospital. The patients were recalled for MoM THA screening according to a register of patients and were consecutively asked for consent to participate in the study. The data were collected from an electronic patient database of the Hospital.

All of the images and blood tests were taken between April 2014 and February 2015, an average of 50 (SD 20, min 20, max 115, median 41) months after the arthroplasty. Altogether 8 of the patients had bilateral MoM arthroplasty. No dislocations had occurred, and none of the patients needed revision surgery for any other complication of the arthroplasty. The exclusion criteria and the patients' demographics are presented in Figure 8.

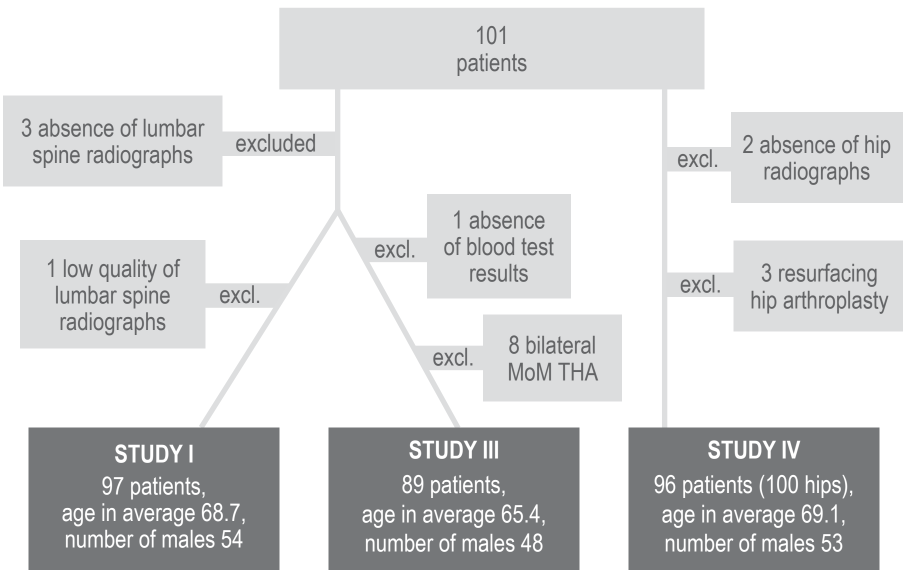


Figure 8. Exclusion criteria and the patients' demographics.

4.2. Methods (studies I, III and IV)

The patients had their lumbar spine and both hips X-rayed from the direction of right-to-left with the left side against the film cassette, while standing straight and comfortable with their arms either crossed over their chest or resting on a horizontal stand. They also underwent anteroposterior radiography of the pelvis while standing and lateral radiography of the replaced hip. Their chromium (Cr) and cobalt (Co) ion blood concentrations (µg/l) were measured from the blood tests.

Pelvic incidence (PI) was defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the center of the axis of the femoral heads (Figure 9). Sacral slope (SS) was defined as the angle between the superior plate of the first sacral vertebra and a horizontal line. Pelvic tilt (PT) was defined as the angle between the line connecting the midpoint of the superior sacral plate to the axis of the femoral heads and the vertical axis. Lumbar lordosis (LL) was measured as the angle between the superior endplates of the first lumbar and first sacral vertebras using the Cobb technique. The center of the replaced hip was defined similarly with respect to the center of a non-operated hip. The used Carestream PACS® imaging software finds the center of the prosthetic femoral head digitally after placing a circle around it. When the replaced hip covered the sight of the other hip, the center of the femoral head was defined as the center of the replaced hip.

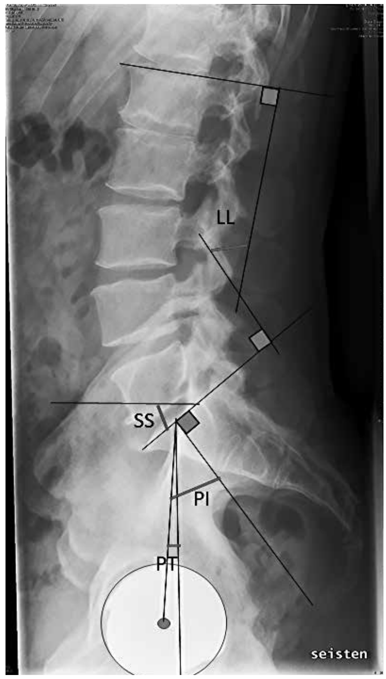


Figure 9. Measurement of pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS) and lumbar lordosis (LL).

The monoblock press-fit acetabular component of a Recap®-M2a-Magnum implant is hemispheric and has a shell thickness of 3 mm. When mated with an insert taper adapter, the modular head is 6 mm smaller than the respective acetabular component. The cup and the head of the Recap®-M2a-Magnum articulation are made of a cobalt-chromium-molybdenum alloy. The stem, taper, and taper adapter of this implant are made of a titanium-aluminum-vanadium alloy. In this study, the point of slight change in the radiological contour between the edge of the shell and the head was considered to be an indicator of the acetabular component rim. The inclination was defined as the direct angle between the line connecting these points and the horizontal line in the anteroposterior pelvic view (Figure 10a). The anteversion was defined as the angle between the line connecting these points and the horizontal

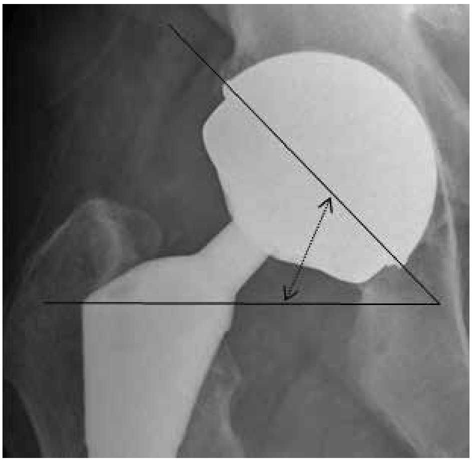


Figure 10a. Measurement of inclination.

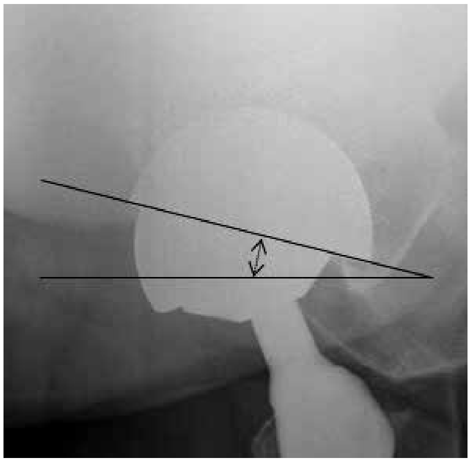


Figure 10b. Measurement of anteversion.

line in the lateral view (Figure 10b). All of the measurements were recorded with an accuracy of 1 degree.

All of the radiographs were assessed using Carestream PACS® imaging software (Carestream Health, Inc., 2011. Version 11.3 turpacs. Rochester, NY: Onex Corp.). Earlier, this kind of digital tool has been reported to be reliable when measuring the total hip implant position (Patel et al. 2011).

4.2.1. Study III

The inclination of the acetabular component was assessed from the pelvis anteroposterior radiographs by a radiologist.

A Shapiro-Wilk test was carried out for data normality appropriate for a dataset smaller than 2000 elements. Therefore, in constructing a regression curve, abnormally distributed data were transformed into lognormal form. The estimates from normally distributed data were reported as means, standard deviations (SD) and ranges. Otherwise, the results were reported as medians and ranges. The Pearson correlation coefficient was used, along with two-tailed p-values (level of significance set at <0.05). A correlation of >0.70 was considered very strong, 0.40 to 0.69 was strong, 0.30 to 0.39 was moderate, 0.20 to 0.29 was weak, and 0.01 to 0.19 indicated no or negligible correlation. All of the calculations were made using IBM® SPSS® Statistics version 22 (IBM® Corp. Released 2013. IBM® SPSS® Statistics for Windows 64 bit, Version 22.0. Armonk, NY: IBM® Corp).

4.2.2. Study I

All of the lumbar spine radiographs were independently assessed by 2 orthopedic surgeons (observer 1 and observer 2). Observer 1 performed the measurements twice (approximately 2 months between measurements), and observer 2 did so only once.

The difference and mean scores were calculated for each measurement pair. The one-sample t-test was used to compare the difference in the scores for each outcome variable: PI, SS, PT, and LL. The results were reported as 2-tailed p-values. A p-value of ≤ 0.05 was considered statistically significant, referring to the systematic over- or underestimation of a measured angle. The 2-way random model intra-class correlation coefficient (ICC) was used to quantify the degree to which an observer´s (intra-observer reliability) or 2 observers' (inter-observer reliability) assessments resembled each other. The results were reported as single-measure ICCs, describing how reliable it is to use only 1 observer, and as average-measure ICCs, describing the reliability of agreement between 2 observers. Cronbach's alpha was also reported. Bland-Altman plots were constructed for each outcome variable. The difference between the 2 measurements per subject was plotted against the mean of the 2 measurements. As suggested previously for samples greater than 60, 95% limits of agreement (95% LA) were calculated by using the following equation: 95% LA = mean ± 1.96* standard deviation (Bland & Altman 1986). The linear regression model was used to detect the potential asymmetry of a plot, a proportional bias occurring when significantly more estimates were observed either above or below the mean line (reported as a 2-tailed p- value). Spearman's rank correlation coefficient was calculated for checking the agreement dependency of the mean of the 2 measurements if the spread of the differences increased with an increasing mean of the observations. We were especially interested in obtaining the absolute error of the measurements regardless of the direction of the difference. Therefore, all of the difference estimates were transformed to positive by taking the square root of each squared difference estimate. Due to this transformation, more observations were grouped close to a zero difference, and the normal distribution became positively skewed. Thus the lognormal distribution was calculated using a decimal logarithm. The means and 95% confidence intervals (95% CIs) were calculated for each outcome variable from the lognormal distribution and then back-transformed into degrees. We accepted that the 95% CIs became asymmetrical because of these steps. All of the calculations were made using IBM® SPSS® Statistics version 22 (IBM® Corp, released in 2013: IBM® SPSS® Statistics for Windows 64 bit, Version 22.0. Armonk, NY, IBM® Corp).

4.2.3. Study IV

The radiographs of the pelvis and the replaced hip were assessed by two independent researchers; both were orthopedic surgeons. One of the observers repeated the assessments after 1 week.

The distributions of all the interval variables were tested for normality. The estimates from normally distributed data were reported as means, standard deviations (SD) and ranges. Otherwise, the results were reported as medians, interquartile ranges (IQR), and ranges. The results were accompanied by 95% confidence intervals (95% CIs). The two-way mixed effects model of the ICC was used to quantify the degree to which the observers' assessments resembled each other. The results were reported as single-measure ICCs, describing how reliable it is to use only one observer, and as average measure ICCs, describing the reliability of agreement between two observers. The ICC was interpreted as follows: 0 to 0.2 poor agreement, 0.3 to 0.4 fair agreement, 0.5 to 0.6 moderate agreement, 0.7 to 0.8 strong agreement, and >0.8 almost perfect agreement. Cronbach's alpha was also reported considering the alpha as follows: ≥0.9 excellent, 0.9 to 0.8 good, 0.8 to 0.7 acceptable, 0.7 to 0.6 questionable, 0.6 to 0.5 poor, and < 0.5 unacceptable. Bland Altman plots were constructed for each outcome measurement pair, plotting the difference between the 2 measurements per subject against the mean of 2 measurements (Bland & Altman 1986). The ICCs were calculated using IBM® SPSS® Statistics, version 22 (IBM® Corp. Released 2013. IBM® SPSS® Statistics for Windows 64 bit, Version 22.0. Armonk, NY: IBM® Corp). All of the other analyses were performed using Stata/IC Statistical Software: Release 14. College Station (StataCorp LP, TX, USA).

4.3. Methods used in the systematic review and quantitative analysis (Study II)

The Cochrane Controlled Trials Register (CENTRAL), MEDLINE (via PubMed), CINAHL and SCOPUS databases were searched in February 2017. The references of identified articles and reviews were also checked for relevancy.

The criteria for considering studies for this review were based on the PICO (Population, Intervention, Comparison, and Outcome) framework as follows:

- Adults with hip disorders, excluding malignancy and acute trauma. Observational and clinical studies published in peer-reviewed journals, excluding theses, conference proceedings, and guidelines. No restrictions based on the time of publication or language. Abstract available.

- Intervention not applicable
- Comparison not applicable
- Outcome primary: risk ratios or odds ratios; secondary any outcome

Two independent reviewers screened the titles and abstracts of the articles and assessed the full texts of potentially relevant studies. Disagreements between the reviewers were resolved by consensus or by a third reviewer. The methodological quality of the included trials was not rated. The ultimate goal of the review was to evaluate the available evidence on the topic quantitatively. Therefore, when data were extracted, more records were omitted due to an inability to provide the statistics needed for the analysis or as being subsets of the same study. For example, a study was excluded if the average figures of the PI were not reported. The data needed for a quantitative analysis were extracted from the included trials using a standardized form based on recommendations found in the Cochrane Handbook for Systematic Reviews of Interventions, 5.1.0 Edition, part 7.6.9 (Cochrane Collaboration).

In the statistical analysis, when not reported, a standard deviation (SD) was calculated from a range as: SD = (Maximum Minimum) 4. The pooled average estimates (M) of several studies were calculated without weighting the studies according to their variance. The pooled SDs of several studies were calculated as ('n' sample size): SDpooled = Ö [(n1–1)*SD12 + (n2–1)*SD22 + … + (nk–1)*SDk2) (n1 + n2 + … + nk k)]. The 95% confidence intervals (95% CI) were calculated as: 95% CI = mean ± 1.96 × (SD/Ön). All of the calculations were made using Microsoft® Excel® 2013.

5. Results

5.1. The correlation between pelvic incidence and the blood levels of chromium and cobalt after metal-on-metal arthroplasty (Study III)

Of the 89 patients in study III, 3 had had MoM resurfacing and 86 had had a MoM total hip replacement. In addition to the MoM, 15 patients had earlier undergone other types of hip replacement on the contralateral side.

The mean angle for the PI was 55.8 (SD 11.2, range 35–83) degrees. The respective figures for the inclination of the acetabular component were 41.5 (SD 7.4, range 22 to 60) degrees. The Cr ion blood level had a median of 1.6 (range 0.7 to 13.6) µg/l. The respective median value for the Co ion blood concentration was 1.5 (range 0.4 to 29.6) µg/l. No significant correlations were observed between the PI or inclination angles and the blood levels of the Cr or Co ions (Table 1). There were also no correlations between the metal ion blood levels and the length of follow-up or gender. The correlation coefficients varied from –0.02 to 0.2, and all of the p-values were >0.05.

Table 1. Correlation (Pearson r) between metal ion blood levels and pelvic incidence (PI), inclination of the implant acetabular component, length of follow-up, and gender

Measurement	Chromium ion blood concentration		Cobalt ion blood concentration	
	Correlation coefficient	p-value	Correlation coefficient	p-value
PI angle	–0.02	0.855	0.01	0.929
Inclination angle	–0.077	0.474	0.036	0.739
Time from surgery to test	–0.031	0.774	0.121	0.260
Gender	0.175	0.10	0.203	0.057

5.2. Intra- and inter-observer reliabilities of measuring pelvic incidence, sacral slope, pelvic tilt, and lumbar lordosis in lateral radiographs of the lumbar spine of standing subjects after hip arthroplasty (Study I)

Of the 97 patients included in Study I, 90 underwent unilateral arthroplasty, and for 7 the arthroplasty was bilateral. Altogether 17 of those who underwent the unilateral procedure had undergone some other type of hip replacement in the contralateral hip. The average scores for PI, SS, PT and LL are presented in Table 2. The intra- and inter-observer reliability is presented in Table 3.

Table 2. Mean scores and standard deviations (SDs) for pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT) and lumbar lordosis (LL).

	Mean	SD
First assessment by observer 1		
PI	55.6	11.0
SS	38.6	9.5
PT	17.2	8.0
LL	53.5	12.5
Second assessment by observer 1		
PI	54.7	11.0
SS	37.9	10.0
PT	17.2	8.1
LL	53.7	14.0
Assessment by observer 2		
PI	51.9	11.3
SS	35.1	9.9
PT	16.6	8.8
LL	50.8	14.9

Table 3. Intra- and inter-observer reliability of measuring pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and lumbar lordosis (LL).

	Intra-observer reliability				Inter-observer reliability			
	PI	SS	PT	LL	PI	SS	PT	LL
Sample size	97	97	97	97	97	97	97	97
Error between observers or observations*								
Mean, degrees	1.41	1.16	0.49	1.75	2.82	2.44	0.73	2.28
Lower 95% confidence interval	0.98	0.78	0.31	1.22	2.04	1.78	0.48	1.55
Upper 95% confidence interval	2.03	1.74	0.76	2.51	3.9	3.35	1.13	3.34
Difference between observations or observers**								
Mean difference, degrees	–0.89	–0.78	–0.08	0.16	–3.76	–3.55	–0.66	–2.71
Standard deviation, degrees	3.60	3.79	2.08	4.10	4.98	4.22	2.94	5.83
Lower 95% limit of agreement	–7.94	–8.21	–4.16	–8.20	–13.52	–11.82	–6.42	–14.14
Higher 95% limit of agreement	6.17	6.65	4.00	7.88	6.00	4.72	5.10	9.72
One-sample t-test, 2-tailed p-value	0.017	0.044	0.696	0.693	0.000	0.000	0.030	0.000
Test for proportional bias, 2-tailed p-value	0.930	0.175	0.712	0.000	0.571	0.291	0.013	0.040
Intraclass correlation coefficient (ICC)								
Single measures ICC	0.94	0.92	0.97	0.95	0.85	0.85	0.94	0.88
Lower 95% confidence interval	0.92	0.89	0.95	0.93	0.57	0.49	0.91	0.81
Higher 95% confidence interval	0.97	0.95	0.98	0.97	0.93	0.94	0.96	0.94
Average measures ICC	0.97	0.96	0.98	0.98	0.92	0.92	0.97	0.94
Lower 95% confidence interval	0.96	0.94	0.98	0.96	0.73	0.66	0.95	0.89
Higher 95% confidence interval	0.98	0.97	0.99	0.98	0.97	0.97	0.98	0.97
Cronbach's alpha	0.97	0.96	0.98	0.98	0.95	0.95	0.97	0.95
Correlation between the mean difference and average scores for each assessed pair								
Correlation coefficient (Spearman's)	0.05	0.18	–0.03	0.02	0.06	0.03	0.25	0.33
2-tailed p-value	0.624	0.086	0.757	0.880	0.541	0.738	0.013	0.001

* Regardless of the direction of the difference between the observations.
** Distinguishing the direction of the difference between the observations.

5.2.1. Intra-observer reliability

The Bland-Altman plots for intra-observer reliability are presented in Figure 11. For all 4 measures, the absolute error between 2 observations was less than 2 degrees. The mean difference was less than 1 degree with the LA varying between 2 to 4 degrees. For the PI and SS, a p-value of < 0.05 referred to the over- or underestimation of the measured angles when the 1st and 2nd measurements were compared. For all 4 measures, both the single and average ICC measures showed a perfect correlation between the repeated measures, the estimates being 0.92 to 0.97, respectively. In the case of LL, there was a slight proportional bias, with more estimates being placed below the mean line than above it. For all 4 measures, the correlation between the mean difference and the average scores of each assessed pair was small and statistically nonsignificant.

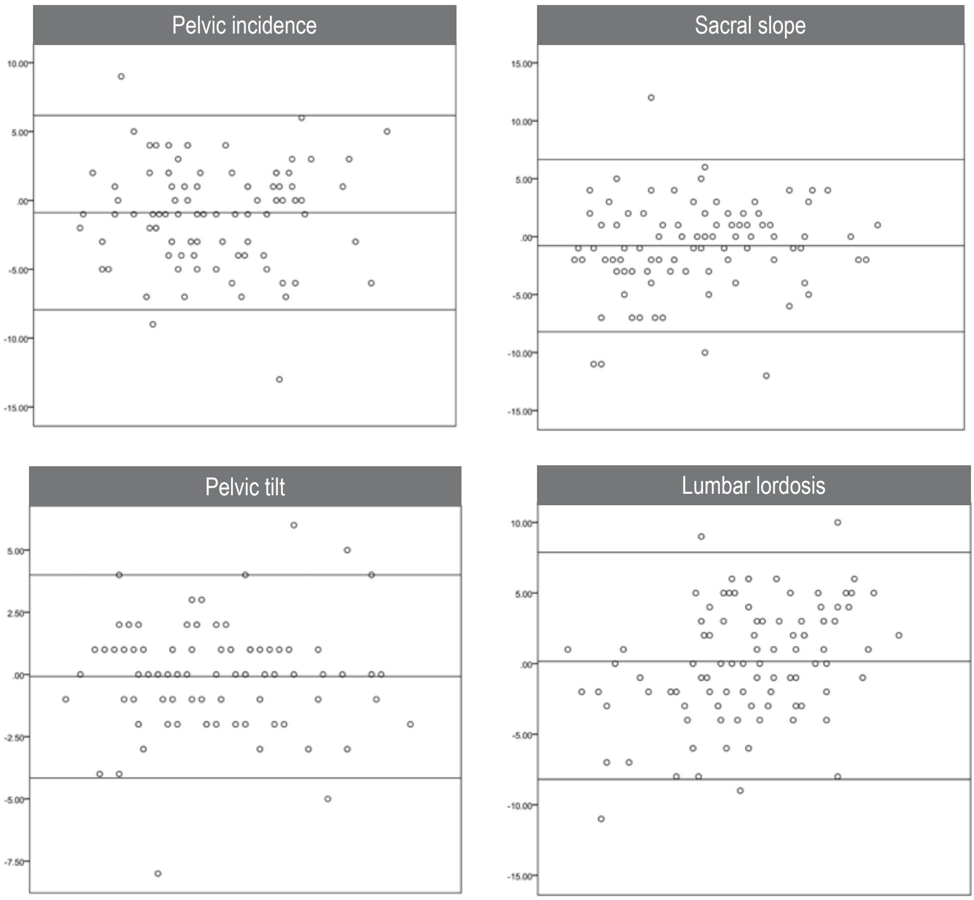


Figure 11. Bland-Altman plots of intra-observer reliability. (The circles represent paired repeated measures obtained for 1 observer. The scores of the difference between the paired observations are placed on the Y-axis, and the mean values of each pair are located on the X-axis. The middle line denotes the mean difference values. The upper and lower lines denote 95% LA.)

5.2.2. Inter-observer reliability

Bland-Altman plots for the inter-observer reliability are presented in Figure 12. For PI, SS and LL, the absolute error was less than 3 degrees. For PT, it was less than 1 degree. The mean difference varied between 3 and 4 degrees for PI, SS and LL, and it was less than 1 degree for PT. For all 4 measures, the p-value of the t-test was < 0.05 in reference to the over- or underestimation of the angles measured by 2 observers. For all 4 measures, both the single and average measures ICC showed a very strong correlation between the observations, the estimates ranging from 0.85 to 0.94. In the case of the PT and LL, there was a slight proportional bias with more estimates below the mean line than above it. For all 4 measures, the correlation between the mean difference and the average scores for each assessed pair was low, being statistically non-significant for PI and SS and significant for PT and LL.

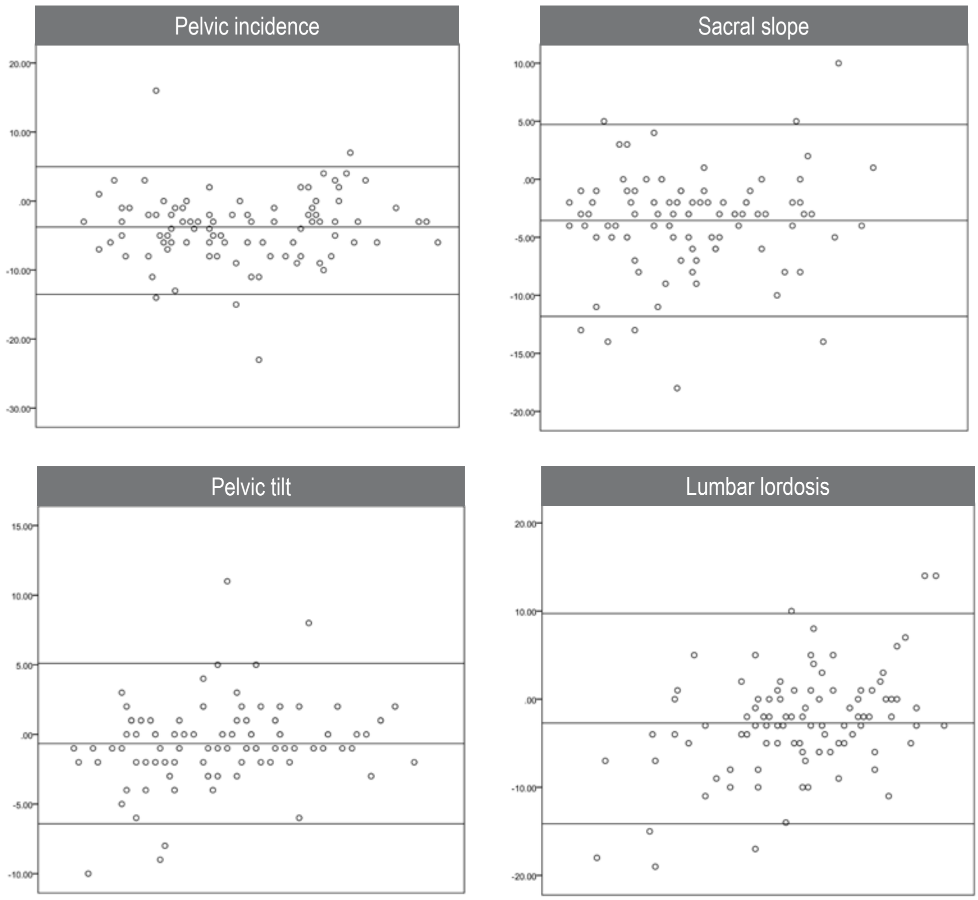


Figure 12. Bland-Altman plots of the inter-observer reliability. The circles represent paired measures obtained by separate observers. The scores of the difference between the paired observations are placed on the Y-axis, and the mean values of each pair are located on the X-axis. The middle line denotes the mean difference values. The upper and lower lines denote the 95% LA).

5.3. Intra- and inter-observer reliability of measuring the acetabular component inclination and anteversion angles of a large-diameter MoM total hip implant by using plain radiographs (Study IV)

Of the 100 replaced hips in study IV, 64 were right hips and 36 left hips. All of the evaluated implants were well osteo-integrated. One image was excluded from the anteversion assessment due to its low quality. The average, minimum, and maximum scores for the measurements of inclination and anteversion are presented in Table 4.

Table 4. The mean scores and standard deviations (SDs) for the inclination and anteversion.

Repeated measures	Mean	Standard deviation	Minimum	Maximum
Observer 1 (first assessment)				
Inclination	43.0	7.3	26	59
Anteversion	20.7	10.4	–6	58
Observer 1 (second assessment)				
Inclination	43.1	7.3	24	58
Anteversion	20.7	10.6	–5	59
Observer 2				
Inclination	42.5	7.5	24	62
Anteversion	20.0	10.6	–7	59

5.3.1. Inclination

In all of the measurements, the inclination angle averaged 43 degrees, varying only slightly. The comparison of the inter-observer measurements showed a median difference of 1 (IQR 0 to 2, range 0 to 9) degree. Assessed by the ICC, the inter-observer repeatability was nearly perfect: the single-measures ICC being 0.97 (95%CI 0.96 to 0.98) and the average-measures ICC being 0.99 (95% CI 0.98 to 1.0). The Cronbach's alpha was 0.99. The intra-observer median difference was 1 (IQR 1 to 2, range 0 to 7) degree. The intra-observer repeatability of the assessment was also nearly perfect: the single measures ICC being 0.96 (95%CI 0.95 to 0.98) and the average-measures ICC being 0.98 (95%CI 0.97 to 0.99). The Cronbach's alpha was 0.98. The Bland Altman plots confirmed the similarity of the repeated measures estimates (Figure 13).

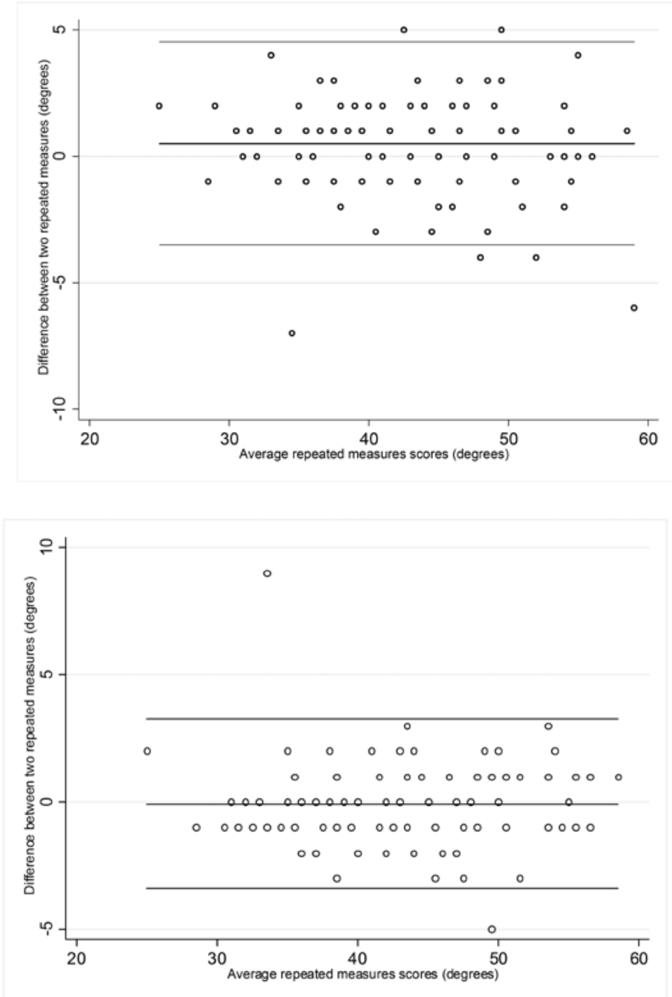


Figure 13. Bland Altman plots of the intra-observer (12a) and inter-observer (12b) reliability of the inclination measurements. The circles represent paired measures. The middle line denotes the mean difference values. The upper and lower lines denote the 95% LA.

5.3.2. Anteversion

In three measurements, the anteversion angle varied slightly on the average from 20 to 21 degrees. The comparison of the inter-observer measurements showed a median difference of 1 (IQR 0 to 1, range 0 to 10) degree. As assessed by the ICC, the inter-observer repeatability was nearly perfect: the single measures ICC being 0.99 (95%CI 0.98 to 0.99) and the average measures ICC being 0.99 (95%CI 0.99 to 1.0). Cronbach's alpha was 0.99. The intra-observer median difference was 1 (IQR 1 to 1, range 0 to 10) degree. The intra-observer repeatability of assessment was also nearly perfect: the single measures ICC being 0.99 (95%CI 0.98 to 0.99) and the average measures ICC being 0.99 (95%CI 0.99 to 1.0). Cronbach's alpha was 0.99. In this case, as well, the Bland Altman plots confirmed the similarity of the repeated measures estimates (Figure 14).

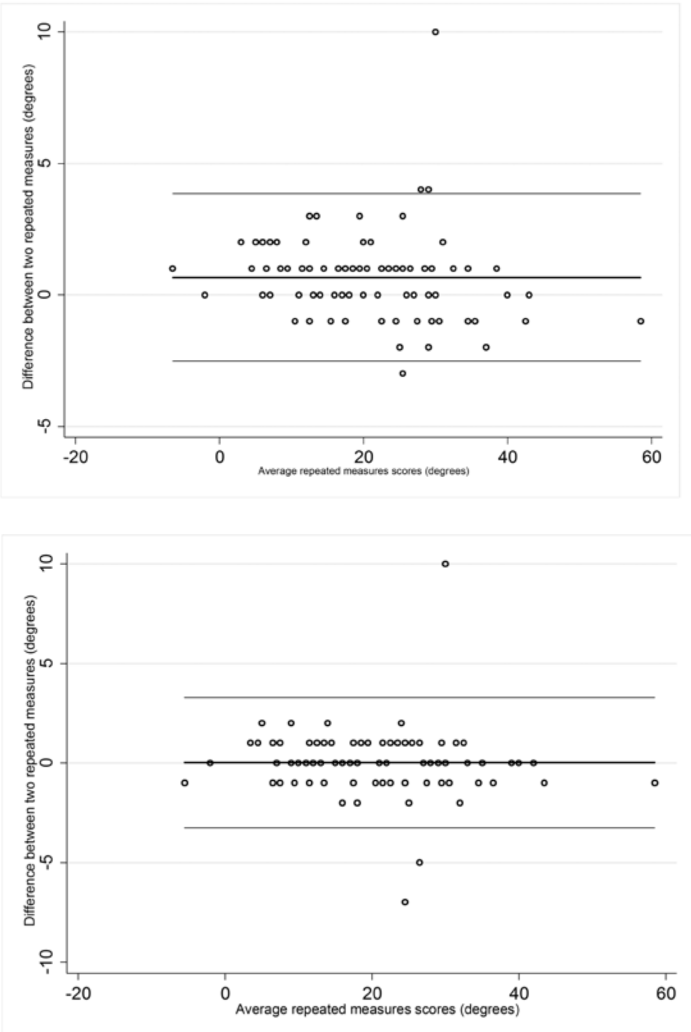


Figure 14. Bland Altman plots of the intra-observer (13a) and inter-observer (13b) reliability of the anteversion measurements. The dots represent paired measures. The middle line denotes the mean difference values. The upper and lower lines denote 95% LA.

5.4. The connection between pelvic incidence and hip disorders – a systematic review and quantitative analysis (Study II)

The search for systematic reviews resulted in 326 records, of which 223 were screened based on their titles and abstracts, and 52 were based on their full texts (Figure 15). The collection of 15 studies was analyzed qualitatively in more detail (Yoshimoto et al. 2005, Blondel et al. 2009, Sariali et al. 2009, Bendaya et al. 2015, Bredow et al. 2015, Gao et al. 2015, Gu et al. 2015, Weng et al. 2015, Eyvazov et al. 2016, Hellman et al. 2016, Jo et al. 2016, Ochi et al. 2016, Weinberg et al. 2016, Weng et al. 2016, Ochi et al. 2017). After the exclusion of the study by Gu et al. (2015), which did not report the statistics needed for a quantitative analysis (average figures of PI) and another study by Weng and coworkers (2015), which was a subset of the study published in 2016 by the same team (Weng et al. 2016), the final sample for the quantitative analysis comprised 13 studies.

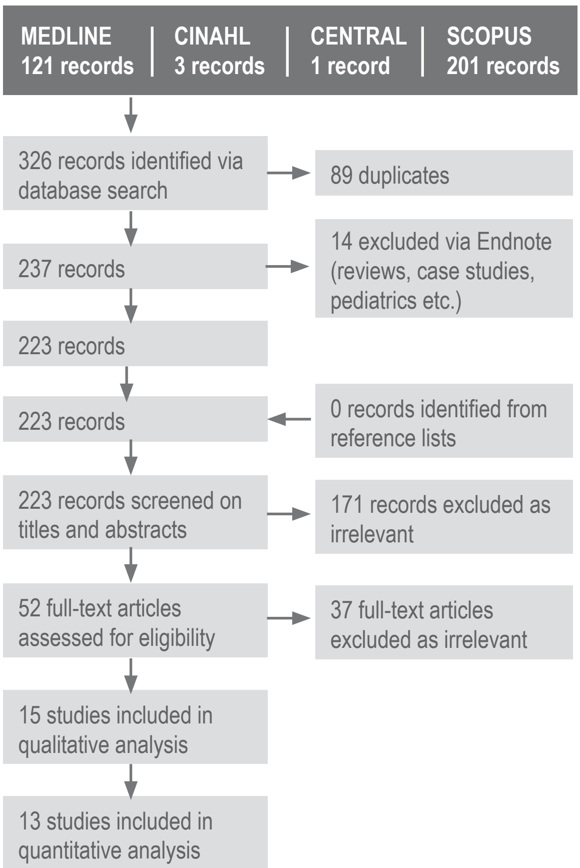


Figure 15. Search and data extraction flow.

All of the 15 studies had been published within the last 8 years. Most of the included studies were retrospective. Of the 15 included studies, 10 targeted patients with coxarthrosis, 2 studies concerned patients with ankylosing spondylitis, 2 studies focused on patients with FAI, and 1 trial dealt with subchondral insufficiency fractures (SIF). Reference groups were used in 7 studies: in 6 studies reference samples had been drawn from healthy populations (of them, 1 sample was matched), and 1 control group was made up of patients with low back pain. Six studies were cross-sectional, while the rest assessed spinopelvic parameters before and after total hip replacement. Lateral standing radiography was used in all of the studies, except 1 (Weinberg et al. 2016), the research groups, containing, in addition, in some cases, the 3D reconstruction technique, sitting radiography, computed tomography, and magnetic resonance imaging. The inclusion and exclusion criteria were considered appropriate, and they were clearly defined in all of the studies except 1 (Gu et al. 2015).

The sample sizes of the included studies varied from 19 to 150 patients (Table 5). As expected, the patients with coxarthrosis and subchondral insufficiency fractures were older (around 60 years or older) than the patients with ankylosing spondylitis or FAI (<40 years). Across the samples, there was a slight predomination of women. The estimates of PI varied more than 10 degrees from 46.7 (SD 3.7) to 58.5 (SD 14.0). The authors of a few of the original studies had concluded that PI may play some role in hip disorders even though the sample sizes were considered underpowered in detecting statistically significant results. Two studies concluded that a higher PI may contribute to the development of coxarthrosis (Yoshimoto et al. 2005, Bredow et al. 2015). However, 1 study by Weng and coworkers (2015) reported that PI may not be involved in coxarthrosis. The study by Gao and coworkers (2015) reported that PI may correlate with quality of life, body pain, vitality and emotional role for patients with ankylosing spondylitis when they were compared with patients gathered before and after hip replacement. The study by Hellman and coworkers (2016) stated that the PI for patients with FAI was lower than that of the general population, 49.3 (SD 12.3) versus 55.0 (SD 10.6), respectively. The study by Weinberg and coworkers (2016) confirmed this finding, specifying further that this effect only exists for the Cam type of FAI.

To form a reference population of asymptomatic individuals, the "healthy" groups used in the studies evaluated in this review, along with those in the reports cited in the included studies, were used (Legaye et al. 1998, Roussouly et al. 2005, Vialle et al. 2005, Legaye 2009, Sariali et al. 2009, Weng et al. 2015, Jo et al. 2016, Weinberg et al. 2016). This way, the reference "healthy" sample comprised 777 persons (Table 6 and Figure 15). Their genders were equally distributed, and they were younger [38.9 (SD 10.6) years] than their symptomatic counterparts, except in the studies on ankylosing spondylitis and FAI. For this asymptomatic group, the pooled average estimate of pelvic incidence was 52.9 (SD 10.1) degrees. The estimate showed a relatively narrow 95% CI of 52.2 to 53.6 degrees. For the subpopulation of patients with coxarthrosis (pooled n=602 subjects), the pooled mean estimate of pelvic incidence was 54.0 (SD 10.5) degrees with a 95% CI of 53.2 to 54.8 degrees overlapping the 95% CI of the estimate pooled from an asymptomatic population. Figure 16 presents these

Table 5. Main relevant results of the included studies (FAI = femoroacetabular impingement, PI = pelvic incidence, PT = pelvic tilt, SIF = subchondral insufficiency fracture).

Study	Sample size	Gender (women)	Age, mean (SD), years
Hip osteoarthritis			
Bendaya 2015	Coxarthrosis: 30 Healthy: 30	Coxarthrosis 60% Healthy: 47%	Coxarthrosis: 59.5 (15.6) Healthy: 46.0 (12.4)
Blondel 2009	50	48%	64.0 (range 47 to 81)
Bredow 2015	20	40%	64.1 (14.4) a
Eyvazov 2016	28	61%	61.7 (6.4)
Ochi 2016	74	81%	65.5 (13.4) b
Ochi 2017	92	84%	67.5 (10.1)
Sariali 2009	Coxarthrosis: 89 Healthy: 100	Coxarthrosis: 58% Healthy: 45%	Coxarthrosis: 58.2 (2.0) Healthy: 51.0 (10.0)
Weng 2016	Coxarthrosis: 69 Healthy: 64	Coxarthrosis: 64% Healthy: 56%	Coxarthrosis: 62.7 (9.9) Healthy: 58.0 (10.6)
Weng 2015 f	Coxarthrosis: 58 Healthy: 64	Coxarthrosis: 64% Healthy: 56%	Coxarthrosis: 59.0 (11.9) Healthy: 58.0 (10.6)
Yoshimoto 2005	Coxarthrosis: 150 Low back pain: 150	Coxarthrosis: 80% Low back pain: 80%	Coxarthrosis: 61.1 (11.1) Low back pain: 58.9 (11.7)
Ankylosing spondylitis			
Gao 2015	58	2%	32.7 (3.1) d
Gu 2015	29	0%	37.7 (9.24)
Femoroacetabular impingement (FAI)			
Hellman 2016	FAI: 60 Healthy: 300	FAI: 50% Healthy: 37%	FAI: 35.4 (12.0) e Historical controls: 32.6 (9.3) e
Weinberg 2016	Cam type: 21 Retroverted type: 19 Mixed type: 25 Healthy: 27	All together: 48%	All together: 34.0 (3.0)
Subchondral insufficiency fracture (SIF)			
Jo 2016	SIF: 37 Healthy: 37	SIF: 89% Healthy: 89%	SIF: 70.5 (7.4) Healthy: 70.7 (5.2)

a Exceptionally wide range 26 to 91 years;
b Exceptionally wide range 27 to 86 years;
c Exceptionally wide range 29 to 90 for coxarthrosis and 25 to 85 degrees for low back pain;

findings in the form of a forest plot. The figure shows that CIs of only 4 studies did not overlap the 95% CI calculated for an asymptomatic population: 2 studies on coxarthrosis (Yoshimoto et al. 2005, Weng et al. 2015), 1 study on mixed FAI (Weinberg et al. 2016), and 1 study on ankylosing spondylitis (Gao et al. 2015).

	Mean pelvic incidence (PI) estimates (SD), degrees	Authors' comments and conclusions relevant to this review
	Coxarthrosis: 56.3 (11.5) Healthy: 52.1 (11.9)	PI may have been underpowered. Contrary to the classical description, the difference in the sacral slope relates more to a difference in the geometric parameter of PI than to the functional parameter of PT.
	56.0 (range 40.0 to 87.0)	None
	53.9 (13.1)	The initial PI of a few patients was above average, but the small sample size limited the results.
	50.0 (range 35.0 to 60.0)	None
	54.7 (13.6)	Nonsignificant results regarding the role of PI
	51.2 (11.2)	Patients with larger a PI had poorer clinical outcomes.
	Coxarthrosis: 51.7 (5.0) Healthy: 52.7 (9.0)	None
	Coxarthrosis: 49.3 (11.1) Healthy: 46.3 (9.3)	None
	Coxarthrosis: 49.0 (10.8) Healthy: 46.3 (9.3)	PI might not be involved in coxarthrosis.
	Coxarthrosis: 58.5 (14.0) c Low back pain: 51.9 (13.4) c	A higher PI at a young age may contribute to the development of coxarthrosis.
	50.0 (4.4)	The PI angle may correlate with life quality, body pain, vitality and emotional role in patients with ankylosing spondylitis.
	Range 53.5 to 82.0	None
	FAI: 49.3 (12.3) Healthy: 55.0 (10.6)	Lower PI in the patients with FAI than in the general population
	Cam type: 50.8 (4.6) Retroverted type: 51.0 (4.6) Mixed type: 46.7 (3.7) Healthy: 56.1 (4.4)	Mixed-type FAI may develop as a response to decreased pelvic incidence. The pelvic incidence figures did not differ from those of the healthy group in the Cam and retroverted types.
	SIF: 54.3 (12.2) Healthy: 55.4 (8.3)	None

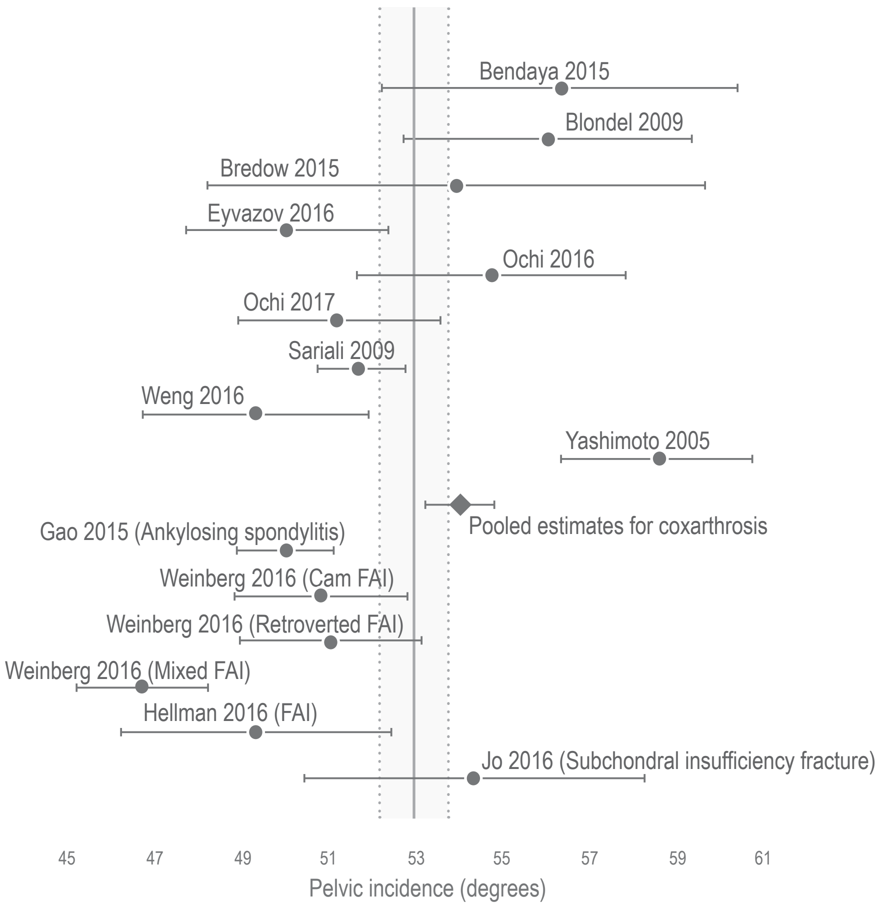
d Figures are reported for the fi nal sample size (n = 47) excluding one patient;
e Exceptionally wide range 20 to 70 (FAI) and 18 to 53 (healthy) years;
f Subgroup of the study by Weng et al. 2016.

Table 6. Pelvic incidence estimates reported by the included studies and their pooled figures along with those for asymptomatic population.

Study	n	Women	Age	SD	Mean	SD	95%CI	
							Lower	Upper
Coxarthrosis								
Bendaya 2015	30	52%	59.5	15.6	56.3	11.5	52.2	60.4
Blondel 2009	50	48%	64.0	8.5a	56.0	11.8 b	52.7	59.3
Bredow 2015	20	40%	64.1	14.4	53.9	13.1	48.2	59.6
Eyvazov 2016	28	61%	61.7	6.4	50.0	6.3 b	47.7	52.3
Ochi 2016	74	81%	65.5	13.4	54.7	13.6	51.6	57.8
Ochi 2017	92	68%	67.5	10.1	51.2	11.2	48.9	53.5
Sariali 2009	89	58%	58.2	2.0	51.7	5.0	50.7	52.7
Weng 2016b	69	64%	62.7	9.9	49.3	11.1	46.7	51.9
Yoshimoto 2005	150	80%	61.1	11.1	58.5	14.0	56.3	60.7
Pooled estimates	602	67%	62.7	10.1	54.0	10.5	53.2	54.8
Ankylosing spondylitisc								
Gao 2015	58	7%	32.7	3.1	50.0	4.4	48.9	51.1
Femoroacetabular impingement (FAI)								
Hellman 2016	60	50%	49.3	12.3	49.3	12.3	46.2	52.4
Weinberg 2016								
Cam type	21	43%	34.0	5.0	50.8	4.6	48.8	52.8
Retroverted type	19	53%	36.0	7.0	51.0	4.6	48.9	53.1
Mixed type	25	48%	34.0	3.0	46.7	3.7	45.2	48.2
Subchondral insufficiency fracture (SIF)								
Jo 2016	37	89%	70.5	7.4	54.3	12.2	50.4	58.2
Asymptomatic samples								
Jo 2016	37	89%	70.7	5.2	55.4	8.3	52.7	58.1
Legaye 1998	49	43%	24.0	5.8	53.2	10.3	50.3	56.1
Legaye 2009	40	58%	44.0	17.0	50.0	12.0	46.3	53.7
Roussouly 2005	160	54%	27.0	7.5 b	51.9	10.7	50.3	53.6
Sariali 2009	100	55%	51.0	10.0	52.7	9.0	50.9	54.5
Vialle 2005	300	37%	35.4	12.0	54.7	10.6	53.5	55.9
Weng 2015	64	58%	58.0	10.6	46.3	9.3	44.0	48.6
Weinberg 2016	27	48%	33.0	5.0	56.1	4.4	54.4	57.8
Pooled estimates	777	47%	38.9	10.4	52.9	10.1	52.2	53.6

a Calculated from reported range as SD = (maximum – minimum)/4;
b Study by Weng et al. 2015 removed as a subset of the study by Weng et al. 2016;
c Study by Gu et al. 2015 was dropped out from the quantitative analysis—no mean pelvic incidence was reported.

Figure 16. Forest plot of the pelvic incidence estimates reported by the included studies and their pooled figures, along with those for an asymptomatic population. The solid line delineates the pooled average estimate of pelvic incidence in the asymptomatic population. The broken lines indicate the 95% confidence intervals of the estimates. The diamond represents the pooled estimate of pelvic incidence for patients with coxarthrosis.



6. Discussion

The systematic review of the literature did not find strong evidence that pelvic incidence plays any substantial role in hip disorders. However, the results suggested that a lower pelvic incidence may be associated with FAI (at least its mixed type) and hip problems among patients with ankylosing spondylitis. The evidence on the association between pelvic incidence and hip OA remained inconclusive.

The main weakness of the review lies in the weaknesses and the scopes of the included studies. Most of the studies were retrospective and underpowered. Only a few focused on pelvic incidence as a main target. For the rest, pelvic incidence was only a secondary outcome or a part of the spinopelvic sagittal alignment totality. The study designs, reference groups, settings and methods varied widely, leading to an incapability to perform a formal meta-analysis or to analyze systematically the methodological quality of the studies. In its present form, the quantitative analysis reported in this review should be generalized with caution, rather as an uncertain predisposition than as an exact recommendation. Concerning especially OA of the hip, it is also possible that different OA subgroups secondary in etiology disappear under the diagnosis of OA and thus eliminate deviating PIs.

Of all the existing hip disorders, only 4 had been studied regarding the topic thus far. A total of 10 of the 15 included studies had been conducted among patients with coxarthrosis. This fact leaves many open questions for upcoming research. The interpretation of the results is especially difficult, as there is no agreement on "normal" reference values for pelvic incidence (Vaz et al. 2002) and because there is a high variance for pelvic incidence estimates among healthy subjects (Vrtovec et al. 2012). Therefore, the evidence is waiting to be established in a large population-based study on the topic.

It is theoretically possible that MoM hip arthroplasty could act as a model for the motion and wearing of any hip joint since Cr and Co ion blood levels have been proposed as being reliable indicators of hip implant wear (De Smet et al. 2008, Sidaginamale et al. 2013). In this thesis, the correlations between PI or inclination angles and Cr or Co ion blood levels were small, <0.2, and statistically not significant. There were also no correlations between metal ion blood levels and length of follow-up or gender.

In agreement with earlier studies reporting on the stability of metal ion levels of up to 9 years after a MoM hip resurfacing operation, no correlation was found between the metal ion blood levels and length of follow-up (Savarino et al. 2014). Both hip resurfacing and total hip replacements were included in the present sample. However, the number of resurfacings was small, only 3 cases. Furthermore, resurfacings and MoM THAs included were analogous models from the same manufacturer. No significant difference in the metal ion levels between the hip resurfacings and different types of MoM THAs overall has previously been reported (Jantzen et al. 2013). However, when blood metal ion levels are compared between ASR resurfacing and ASR THA (DePuy Orthopaedics, Warsaw, IN, USA), higher ion levels in patients with the ASR THA compared with ASR resurfacing have been reported (Lainiala et al. 2016, Laaksonen et al. 2017). Also in studies with ASR THA, female gender has been found to correlate with the increasing of the levels of metal ions (Galea et al. 2017). The gender did not correlate with the blood metal ion concentration in our study concerning patients with Recap®-M2a-Magnum THA. Of the patients in this study, 15 had also been exposed to metal-on-polyethylene in the replacement of the contralateral hip. It is, however, unlikely that this exposure could significantly affect the results, as an increase in metal ion levels after metal-on-polyethylene hip replacement has previously been found to be minor or nonexistent (Qu et al. 2011, Dahlstrand et al. 2017).

In addition to the pelvic motion related to PI and PT, other factors, such as trunnion-femoral head interface and passive corrosion on the stem surface or high inclination, may affect the rate of wear (De Haan et al. 2008, De Smet et al. 2008, Langton et al. 2008, Bolland et al. 2011). Matthies and coworkers (2014) reported that acetabular orientation explains less than 30% of the variation in metal ion levels, while the rest may be explained by other factors, such as component size and design. Langton and coworkers (2008) reported that the smaller component size of ASR hip resurfacing affected the metal ion concentration. Plain correlations may be insufficient with respect to drawing any definitive conclusions since the relevant risk factors may affect one another. In addition, a sample of less than 90 patients may be insufficient to achieve significant results when the possible weak correlations between PI and implant wear are considered. Possibly a multivariate model, including at least gender, MoM arthroplasty inclination and anteversion, and a more complex analysis of sagittal measurements in a larger sample size may reveal whether there is a weak correlation between spinopelvic complex and THA wear.

The two-dimensional imaging used in this study may have miscalculated the true three-dimensional acetabular component orientation, and particularly the anteversion. The acetabular component may be well-positioned in relation to the inclination, but not in relation to ante- or retroversion. This way, the lack of anteversion assessment in this study may have affected the results. The range of the inclination of the acetabular component in this study was relatively wide; this width, in theory, may have increased the wear of the MoM bearings. However, it has previously been stated that the inclination angle is not associated with an adverse reaction to metal debris when ReCap Magnum THA is used (Bosker et al. 2012).

In this study, excellent intra- and inter-observer reliability was found in the assessment of the position the of MoM THA acetabular components in plain radiographs. The absolute error of agreement was as small as 1 degree for both the inclination and the anteversion.

Several previous studies have stated that acetabular component orientation can be measured reliably on the basis of plain radiographs when applied to metal-on-polyethylene, ceramic-on-ceramic, or ceramic-on-polyethylene bearings (Patel et al. 2011, Nho et al. 2012, Lu et al. 2013, Mahmood et al. 2015). However, there are some potential sources of error in measuring the MoM THA position, because large-diameter, MoM, total arthroplasties are entirely metallic – a femoral head, a taper adapter and a cup. The acetabular component contour is not always clearly visualized. For example, although there is a step between the acetabular component and the large head of the implant, the border may appear obliquely as an ellipse, as it is not perpendicular to the X-rays. In addition, if the acetabular component is obviously mal-positioned at the extremes of the anteversion, the edge is not clearly distinguishable in the anteroposterior view because of the overlapping femoral component. Earlier, Langton et al. (2010) made similar observations when assessing MoM resurfacing hip implants. They found that cup vertices were impossible to identify in the anteroposterior view as the anteversion exceeded 30°. We determined the anteversion from a single cross-table lateral radiograph. Earlier studies on repeated radiographs of the same patient have revealed variation of as much as 20 degrees (Biedermann et al. 2005).

We determined the reliability of measuring radiological anteversion, which differs from a true anteversion. Pelvic tilting induces considerable discrepancy between radiographic and calculated anteversion (Haenle et al. 2007), and it has been found that computer tomography is more accurate than plain radiographs in assessments of anteversion (Ghelman et al. 2009, Davda et al. 2015). However, methods to calculate anteversion from plain antero-posterior radiographs have been presented and found acceptable (Ackland et al. 1986, Lu et al. 2013). It has also been suggested that standardizing the patient position for lateral radiographs gives a more accurate assessment of anteversion (Nunley et al. 2011, McArthur et al. 2012). Unstandardized positioning of patients while imaging is a limitation in our study. The lateral radiography was taken from a lying patient with the opposite lower limb raised out of the way. The position potentially alters the orientation of acetabulum. Generally, evaluating the inclination from plain radiographs is considered acceptable accuracy

(Lewinnek et al. 1978, Kalteis et al. 2006, Haenle et al. 2007, De Haan et al. 2008, Langton et al. 2008).

This was the first study evaluating the repeatability of measuring acetabular cup position after total MoM hip replacement. Thus there was no previous research for a direct comparison with our results. When evaluating resurfacing implants, Reito and coworkers (2012) and Davda and coworkers (2015) reported high ICCs for both inclination and anteversion. Previous studies conducted on bearings other than MoM have also reported high reliability for such measurements (Lu et al. 2013, Mahmood et al. 2015). In this study, the reliability figures were higher than the figures reported in previous research. The reason for the difference remains unknown, hiding possibly in differences in the software used. Another reason may be the fact that the sample was uniform in regard to the design of the hip implant used. The familiarity of an observer with assessing these particular kinds of radiographs may have affected the estimations as well, as occurred in the study of Reito and coworkers (2012).

Previously, the reliability of spinopelvic measurements has been examined among asymptomatic volunteers or patients who have had spinal disorders but intact femoral heads. Measuring PI, SS, PT and LL was found to be reliable in this study also after hip replacement. For all 4 of the assessed measures, the intra-observer error was less than 2 degrees, whereas the inter-observer error ranged from 1 to 3 degrees.

Finding the midpoints of femoral heads on radiographs is not necessary when SS and LL are being assessed. Instead, measurements of PI and PT angles are based on the identification of the midpoints of the femoral heads and the center of the axis connecting them. In lateral spinal radiographs, the large-diameter, metal-on-metal, total hip head may block out the sight of a non-operated femoral head. It is also possible that the midpoint of the femoral head has somewhat changed due to arthroplasty. Therefore, the chance for measurement error may be greater with bilateral hip replacement.

In adolescent idiopathic scoliosis Kuklo and coworkers (2005) have reported a minor difference between the reliability of preoperative versus postoperative measurements of a 4th lumbar vertebra tilt and a Cobb angle. They have partially explained their finding by the fact that overlying implants obscure the endplate. Despite our suspicion that these concerns may have affected the reliability of the measurements in our sample, the reliability figures for all 4 measures were nearly equal, suggesting that the replacement of a femoral head probably does not weaken the reliability of sagittal measurements.

For the most part, our results in measuring the reliability of spinopelvic alignment support the findings of previous studies. Several studies have reported some inter- and intra-observer variation in the assessment of spino-pelvic measures. For example, Hwang and coworkers (2010) reported a standard error of 2 degrees for measurements of LL. Polly and coworkers (1996) found that most repeated measures of lumbar lordosis are within 10 degrees. An error of 2 to 4 degrees has been reported by Vedantam and coworkers (1998) for the assessment of spinal sagittal alignment when PI and PT are not included in the assessment. Berthonnaud and coworkers (2005) have reported an inter-observer error of less than 6 degrees for measurements of PI, SS, PT, and LL, finding, in accordance with our study, the lowest variability for PT. A very small inter- and intra-observer error of less than 1 degree for PI has been reported by Vialle et al. (2006) for a series of 30 patients. In addition, in a study by Maillot and coworkers (2015), the inter-observer mean difference of the sagittal measurement was minimal, 0.1 degrees, with an LA of 7 degrees.

Some weaknesses may have affected the generalization of the findings of this study in assessing the reliability of spinopelvic measurements. Previous studies have suggested that the position of the arms during imaging may affect sagittal alignment (Vedantam et al. 2000, Horton et al. 2005). In our study, the position of the upper limbs was not standardized, even though the patients were asked to stand straight. This practice may have affected the degree of SS, PT, and LL, but not the degree of PI, as it is independent of the standing position or the position of the pelvis. Excellent inter-observer reliability has been previously reported regardless of the observers' skill level (Berthonnaud et al. 2005, Maillot et al. 2015). As shown in Figures 11 and 12, there were several outliers. We can only speculate on their real causes. Previous studies have suggested some sources of variability in the reliability of radiographic measurements of this kind, for example, a transitional vertebra or a variation in the architecture of an endplate (Polly et al. 1996). A transitional vertebra may explain the sporadic differences of more than 10 degrees in the measurements of PT observed in this study. Another example is the unusual shape of the first sacral vertebral endplate due to isthmic spondylolysis or spondylolisthesis, which may also affect the precision of measurement. In this study, the most precise figures were obtained when PT was measured. This result can be explained by the opportunity that the variation in the architecture of a first sacral endplate may affect the degree of SS and LL, but not as much as the degree of PI or PT. The accuracy of the measurements in this study was assured by the precise tools included in Carestream PACS® (0.01 degree-error). The differences between manual and computer-assisted techniques in measurements of spino-pelvic angles have previously been considered small, even though the computer-assisted techniques seemed to be more reliable than manual ones (Wu et al. 2014, Maillot et al. 2015).

Several researchers have considered the proportioning of the THA position to spinopelvic anatomy and balance. Barry et al. (2017) reported that anteversion of a pre-existing THA acetabular component will decrease when any pathological sagittal imbalance is corrected by osteotomy, and they advised spine surgeons to consider the change they cause in the orientation of the acetabulum while spinal osteotomy is being performed. Buckland and coworkers (2015) also noted that sagittal spinal correction after THA can affect the stability of the THA, since acetabular anteversion decreases. On the contrary, performing THA has not been found to change the PT (Blondel et al. 2009, Bredow et al. 2015), even though it often allows more hip extension. However, there are still more conjectures and tips than answers concerning the unquestionable connection between spinal balance and THA positioning, not to mention the entirety of hip disorders, and these factors should be taken into account when surgery is actually performed. Despite the uncertainty, the studies on which this thesis is based provide some valuable knowledge on the topic of interest in a systematic, both qualitative and quantitative, form. The results should be noted in the screening for risk factors of hip disorders, planning surgery, or predicting the course of the disease.

The matter is probably much more complicated than a series of measurements. Not only sagittal imbalance causes pelvic retroversion. In common degenerative lumbar disorders, spinal stenosis, individual flexion of the lumbar spine increases the diameter of the spinal canal and can relieve the symptoms (Schonstrom et al. 1989). Flexion of the lumbar spine can result in pelvic retroversion and an increase in PT as well (Pourtaheri et al. 2017). On the other hand, a unique pelvic anatomy can be related to spinal disorders, and this fact may explain some of the completeness. Some researchers have suggested that a low PI is associated with low back pain (Chaleat-Valayer et al. 2011) and degenerative disc disease in young patients (Barrey et al. 2007), whereas a high PI is, by contrast, associated with facet joint arthritis in the lumbar spine (Jentzsch et al. 2013). Also connection between a high PI and spondylolysis (Mehta et al. 2012) and spondylolytic (Hanson et al. 2002) and degenerative (Morel et al. 2005, Aono et al. 2010) spondylolisthesis has been suggested.

The diversity and inconsistency of the evidence on the topic of this thesis may reflect the fact that, while the significance of pelvic incidence in different disorders was proposed over 3 decades ago, intensive research on the subject is just beginning. The studies included in this review have primarily been conducted very recently, in a narrow 2-year timeframe. Thus one might expect that more data on the matter will appear in a few next years. Pelvic posture and kinematics connected to spinal balance might play a more relevant role in hip disorders than PI does.

Many patients with hip OA no longer have low back pain after THA. Consequently, the traditional order of treatment is to focus on the hips before the spine. Decision-making in clinical practice becomes more complicated when obvious pain-generators overlap, or when necessary operations are extensive.

As the hips are structurally connected to the pelvis and spine, a disorder of one may produce or contribute to a disorder of the other. One may dream of a simple explanation between them, since the connection between the hips and spine via the pelvis is too polymorphic to be explained by any separate anatomical, functional or pathogenic feature. To diagnose and treat these associated disorders will be demanding in the future as well. So far technological methods offer possibilities but not complete decisions. Understanding the complexity of both the spine and the hips and the balance between them is the key to treating the patient in the right order.

7. Conclusions

The present study leads to the following conclusions:

1. No relation was found between pelvic incidence angle and the wear of hip replacement in the studied sample (III).
2. The plain radiograph assessment of the total metal-on-metal acetabular component position and the spinopelvic parameters was found to be reliable. Hip replacement did not weaken the interpretation of spinopelvic alignment (I and IV).
3. Pelvic incidence and hip osteoarthrosis do not seem to be related. There may be a connection between low pelvic incidence and femoroacetabular impingement (II).

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References

Ackland M K, Bourne W B, Uhthoff H K. Anteversion of the acetabular cup. Measurement of angle after total hip replacement. J Bone Joint Surg Br 1986; 68 (3): 409-13.

Alsaleem M, Set K K, Saadeh L. Developmental Dysplasia of Hip: A Review. Clin Pediatr (Phila) 2015; 54 (10): 921-8.

Angadji A, Royle M, Collins S N, Shelton J C. Influence of cup orientation on the wear performance of metal-on-metal hip replacements. Proc Inst Mech Eng H 2009; 223 (4): 449-57.

Aono K, Kobayashi T, Jimbo S, Atsuta Y, Matsuno T. Radiographic analysis of newly developed degenerative spondylolisthesis in a mean twelve-year prospective study. Spine (Phila Pa 1976) 2010; 35 (8): 887-91.

Arokoski J, Kiviranta I. Nivelrikko. In: Ortopedia. (Ed. Kiviranta I JM). Kandidaattikustannus: Helsinki; 2012; 125-36.

Arokoski J, Manninen P, Kröger H, Heliövaara M, Nykyri E, Impivaara O. Musculosceletal disorders and diseases in Finland: hip and knee pain and osteoarthritis. In: Results of Health 2000 Survey. Publications of the National Health Institute; 2007; B25; 37-41.

Aubry S, Marinescu A, Forterre O, Runge M, Garbuio P. [Definition of a reproducible method for acetabular anteversion measurement at CT]. J Radiol 2005; 86 (4): 399-404.

Bae J S, Jang J S, Lee S H, Kim J U. Radiological analysis of lumbar degenerative kyphosis in relation to pelvic incidence. Spine Journal 2012; 12 (11): 1045-51.

Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. Eur Spine J 2007; 16 (9): 1459-67.

Barrey C, Roussouly P, Le Huec J C, D'Acunzi G, Perrin G. Compensatory mechanisms contributing to keep the sagittal balance of the spine. Eur Spine J 2013; 22 Suppl 6: S834-41.

Barry J J, Yucekul A, Theologis A A, Hansen E N, Ames C, Deviren V. Spinal realignment for adult deformity: Three-column osteotomies alter total hip acetabular component positioning. Journal of the American Academy of Orthopaedic Surgeons 2017; 25 (2): 125-32.

Beck M, Kalhor M, Leunig M, Ganz R. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. J Bone Joint Surg Br 2005; 87 (7): 1012-8.

Ben-Galim P, Ben-Galim T, Rand N, Haim A, Hipp J, Dekel S, et al. Hip-spine syndrome: the effect of total hip replacement surgery on low back pain in severe osteoarthritis of the hip. Spine (Phila Pa 1976) 2007; 32 (19): 2099-102.

Bendaya S, Lazennec J Y, Anglin C, Allena R, Sellam N, Thoumie P, et al. Healthy vs. osteoarthritic hips: A comparison of hip, pelvis and femoral parameters and relationships using the EOS® system. Clinical Biomechanics 2015; 30 (2): 195-204.

Berthonnaud E, Dimnet J, Roussouly P, Labelle H. Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. J Spinal Disord Tech 2005; 18 (1): 40-7.

Berthonnaud E, Labelle H, Roussouly P, Grimard G, Vaz G, Dimnet J. A variability study of computerized sagittal spinopelvic radiologic measurements of trunk balance. J Spinal Disord Tech 2005; 18 (1): 66-71.

Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 2005; 87 (6): 762-9.

Bland J M, Altman D G. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1 (8476): 307-10.

Blondel B, Parratte S, Tropiano P, Pauly V, Aubaniac J M, Argenson J N. Pelvic tilt measurement before and after total hip arthroplasty. Orthopaedics and Traumatology: Surgery and Research 2009; 95 (8): 568-72.

Bodin A, Roussouly P. Sacral and pelvic osteotomies for correction of spinal deformities. Eur Spine J 2015; 24 Suppl 1: S72-82.

Bolland B J, Culliford D J, Langton D J, Millington J P, Arden N K, Latham J M. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. J Bone Joint Surg Br 2011; 93 (5): 608-15.

Bosker B H, Ettema H B, Boomsma M F, Kollen B J, Maas M, Verheyen C C. High incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement: a prospective cohort study. J Bone Joint Surg Br 2012; 94 (6): 755-61.

Boulay C, Bollini G, Legaye J, Tardieu C, Prat-Pradal D, Chabrol B, et al. Pelvic incidence: a predictive factor for three-dimensional acetabular orientation-a preliminary study. Journal [serial online]. 2014 Date PMC3976936]; 2014: [9 screens]. Available from: https://www.ncbi.nlm.nih.gov/pubmed/25006461.

Bredow J, Katinakis F, Schlüter-Brust K, Krug B, Pfau D, Eysel P, et al. Influence of hip replacement on sagittal alignment of the lumbar spine: An EOS study. Technology and Health Care 2015; 23 (6): 847-54.

Buckland A J, Vigdorchik J, Schwab F J, Errico T J, Lafage R, Ames C, et al. Acetabular Anteversion Changes Due to Spinal Deformity Correction: Bridging the Gap between Hip and Spine Surgeons. Journal of Bone and Joint Surgery - American Volume 2015; 97 (23): 1913-20.

Chaleat-Valayer E, Mac-Thiong J M, Paquet J, Berthonnaud E, Siani F, Roussouly P. Sagittal spino-pelvic alignment in chronic low back pain. European Spine Journal 2011: 1-7.

Charnley J. Surgery of the hip-joint: present and future developments. Br Med J 1960; 1 (5176): 821-6.

Chimenti P C, Drinkwater C J, Li W, Lemay C A, Franklin P D, O'Keefe R J. Factors Associated With Early Improvement in Low Back Pain After Total Hip Arthroplasty: A Multi-Center Prospective Cohort Analyses. J Arthroplasty 2016; 31 (1): 176-9.

Clohisy J C, Knaus E R, Hunt D M, Lesher J M, Harris-Hayes M, Prather H. Clinical presentation of patients with symptomatic anterior hip impingement. Clin Orthop Relat Res 2009; 467 (3): 638-44.

Cobb J. Outline for the study of scoliosis. American Academy of Orthopaedic Surgeons 1948; (Instructional Course Lectures).

Cochrane Collaboration. Cochrane Handbook for Systematic Reviews of interventions. 5.1.0 ed. The Cochrane Collaboration.

Cuckler J M, Moore K D, Lombardi A V, Jr., McPherson E, Emerson R. Large versus small femoral heads in metal-on-metal total hip arthroplasty. J Arthroplasty 2004; 19 (8 Suppl 3): 41-4.

Dahlstrand H, Stark A, Wick M C, Anissian L, Hailer N P, Weiss R J. Comparison of metal ion concentrations and implant survival after total hip arthroplasty with metal-on-metal versus metal-on-polyethylene articulations. Acta Orthop 2017; 88 (5): 490-5.

Davda K, Smyth N, Cobb J P, Hart A J. 2D measurements of cup orientation are less reliable than 3D measurements. Acta Orthop 2015; 86 (4): 485-90.

De Haan R, Campbell P A, Su E P, De Smet K A. Revision of metal-on-metal resurfacing arthroplasty of the hip: the influence of malpositioning of the components. J Bone Joint Surg Br 2008; 90 (9): 1158-63.

De Haan R, Pattyn C, Gill H S, Murray D W, Campbell P A, De Smet K. Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. J Bone Joint Surg Br 2008; 90 (10): 1291-7.

De Smet K, De Haan R, Calistri A, Campbell P A, Ebramzadeh E, Pattyn C, et al. Metal ion measurement as a diagnostic tool to identify problems with metal-on-metal hip resurfacing. J Bone Joint Surg Am 2008; 90 Suppl 4: 202-8.

DelSole E M, Vigdorchik J M, Schwarzkopf R, Errico T J, Buckland A J. Total Hip Arthroplasty in the Spinal Deformity Population: Does Degree of Sagittal Deformity Affect Rates of Safe Zone Placement, Instability, or Revision? J Arthroplasty 2016; 32 (6): 7.

Devin C J, McCullough K A, Morris B J, Yates A J, Kang J D. Hip-spine syndrome. J Am Acad Orthop Surg 2012; 20 (7): 434-42.

Dumbleton J H, Manley M T. Metal-on-Metal total hip replacement: what does the literature say? J Arthroplasty 2005; 20 (2): 174-88.

Duval-Beaupère G, Schmidt C, Cosson P. A Barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. Ann Biomed Eng 1992; 20 (4): 451-62.

Dzaja I, Syed K. Hip and Knee Osteoarthritis. In: Osteoarhtiris. (Ed. Kapoor M, Mahomed N). Springer International Publishing; 2015; 29-42.

Engesæter I O, Lehmann T, Laborie L B, Lie S A, Rosendahl K, Engesaeter L B. Total hip replacement in young adults with hip dysplasia: age at diagnosis, previous treatment, quality of life, and validation of diagnoses reported to the Norwegian Arthroplasty Register between 1987 and 2007. Acta Orthop 2011; 82 (2): 149-54.

Eyvazov K, Eyvazov B, Basar S, Nasto L A, Kanatli U. Effects of total hip arthroplasty on spinal sagittal alignment and static balance: a prospective study on 28 patients. Eur Spine J 2016; 25 (11): 3615-21.

FAR. Finnish Arthroplasty Register. Available from www.thl.fi/far.

Galea V P, Laaksonen I, Matuszak S J, Connelly J W, Muratoglu O, Malchau H. Mid-term changes in blood metal ion levels after Articular Surface Replacement arthroplasty of the hip. Bone Joint J 2017; 99-B (4 Supple B): 33-40.

Ganz R, Leunig M, Leunig-Ganz K, Harris W H. The etiology of osteoarthritis of the hip: an integrated mechanical concept. Clin Orthop Relat Res 2008; 466 (2): 264-72.

Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock K A. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res 2003; (417): 112-20.

Gao Y, Wang B, Xie Z K, Shen P F, Xu J D, Zheng C, et al. Total hip arthroplasty for ankylosing spondylitis: The spine-pelvis sagittal balance and quality of life. Chinese Journal of Tissue Engineering Research 2015; 19 (4): 516-21.

Gebhart J J, Streit J J, Bedi A, Bush-Joseph C A, Nho S J, Salata M J. Correlation of pelvic incidence with cam and pincer lesions. American Journal of Sports Medicine 2014; 42 (11): 2649-53.

Gebhart J J, Weinberg D S, Bohl M S, Liu R W. Relationship between pelvic incidence and osteoarthritis of the hip. Bone and Joint Research 2016; 5 (2): 66-72.

Ghelman B, Kepler C K, Lyman S, Della Valle A G. CT outperforms radiography for determination of acetabular cup version after THA. Clin Orthop Relat Res 2009; 467 (9): 2362-70.

Glassman S D, Berven S, Bridwell K, Horton W, Dimar J R. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. Spine (Phila Pa 1976) 2005; 30 (6): 682-8.

Greber E M, Pelt C E, Gililland J M, Anderson M B, Erickson J A, Peters C L. Challenges in Total Hip Arthroplasty in the Setting of Developmental Dysplasia of the Hip. J Arthroplasty 2017; 32 (9S): S38-S44.

Gu M, Zhang Z, Kang Y, Sheng P, Yang Z, Zhang Z, et al. Roles of Sagittal Anatomical Parameters of the Pelvis in Primary Total Hip Replacement for Patients with Ankylosing Spondylitis. Journal of Arthroplasty 2015; 30 (12): 2219-23.

Haenle M, Heitner A, Mittelmeier W, Barbano R, Scholz R, Steinhauser E, et al. Assessment of cup position from plain radiographs: impact of pelvic tilting. Surg Radiol Anat 2007; 29 (1): 29-35.

Hanson D S, Bridwell K H, Rhee J M, Lenke L G. Correlation of pelvic incidence with low- and high-grade isthmic spondylolisthesis. Spine (Phila Pa 1976) 2002; 27 (18): 2026-9.

Hart A J, Dandachli W, Schlueter-Brust K, Henckel J, Cobb J. Large ball metal on metal hips obscure cup angle measurement on plain radiographs. Hip Int 2009; 19 (4): 323-9.

Hartmann A, Hannemann F, Lutzner J, Seidler A, Drexler H, Gunther K P, et al. Metal ion concentrations in body fluids after implantation of hip replacements with metal-on-metal bearing--systematic review of clinical and epidemiological studies. PLoS One 2013; 8 (8): e70359.

Heliovaara M, Makela M, Impivaara O, Knekt P, Aromaa A, Sievers K. Association of overweight, trauma and workload with coxarthrosis. A health survey of 7,217 persons. Acta Orthop Scand 1993; 64 (5): 513-8.

Hellman M, Haughom B, Brown N, Fillingham Y, Salata M, Nho S. Pelvic incidence and femoroacetabular impingement-a novel relationship. Arthroscopy - Journal of Arthroscopic and Related Surgery 2013; 29 (12): e196-e7.

Hellman M D, Haughom B D, Brown N M, Fillingham Y A, Philippon M J, Nho S J. Femoroacetabular Impingement and Pelvic Incidence: Radiographic Comparison to an Asymptomatic Control. Arthroscopy 2016.

Horton W C, Brown C W, Bridwell K H, Glassman S D, Suk S I, Cha C W. Is there an optimal patient stance for obtaining a lateral 36" radiograph? A critical comparison of three techniques. Spine (Phila Pa 1976) 2005; 30 (4): 427-33.

Hsieh P H, Chang Y, Chen D W, Lee M S, Shih H N, Ueng S W. Pain distribution and response to total hip arthroplasty: a prospective observational study in 113 patients with end-stage hip disease. J Orthop Sci 2012; 17 (3): 213-8.

Hu J, Qian B P, Qiu Y, Wang B, Yu Y, Zhu Z Z, et al. Can acetabular orientation be restored by lumbar pedicle subtraction osteotomy in ankylosing spondylitis patients with thoracolumbar kyphosis? Eur Spine J 2016.

Hwang J H, Modi H N, Suh S W, Hong J Y, Park Y H, Park J H, et al. Reliability of lumbar lordosis measurement in patients with spondylolisthesis: a case-control study comparing the Cobb, centroid, and posterior tangent methods. Spine (Phila Pa 1976) 2010; 35 (18): 1691-700.

Ito K, Minka M A, 2nd, Leunig M, Werlen S, Ganz R. Femoroacetabular impingement and the cam-effect. A MRI-based quantitative anatomical study of the femoral head-neck offset. J Bone Joint Surg Br 2001; 83 (2): 171-6.

Jackson R P, McManus A C. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. Spine (Phila Pa 1976) 1994; 19 (14): 1611-8.

Jacobsen S, Sonne-Holm S. Hip dysplasia: a significant risk factor for the development of hip osteoarthritis. A cross-sectional survey. Rheumatology (Oxford) 2005; 44 (2): 211-8.

Jantzen C, Jorgensen H L, Duus B R, Sporring S L, Lauritzen J B. Chromium and cobalt ion concentrations in blood and serum following various types of metal-on-metal hip arthroplasties: a literature overview. Acta Orthop 2013; 84 (3): 229-36.

Jentzsch T, Geiger J, Bouaicha S, Slankamenac K, Nguyen-Kim T D, Werner C M. Increased pelvic incidence may lead to arthritis and sagittal orientation of the facet joints at the lower lumbar spine. BMC Med Imaging 2013; 13: 34.

Jo W L, Lee W S, Chae D S, Yang I H, Lee K M, Koo K H. Decreased lumbar lordosis and deficient acetabular coverage are risk factors for subchondral insufficiency fracture. Journal of Korean Medical Science 2016; 31 (10): 1650-5.

Kalteis T, Handel M, Herold T, Perlick L, Paetzel C, Grifka J. Position of the acetabular cup -- accuracy of radiographic calculation compared to CT-based measurement. Eur J Radiol 2006; 58 (2): 294-300.

Kebaish K M, Neubauer P R, Voros G D, Khoshnevisan M A, Skolasky R L. Scoliosis in adults aged forty years and older: prevalence and relationship to age, race, and gender. Spine (Phila Pa 1976) 2011; 36 (9): 731-6.

Kennedy J G, Rogers W B, Soffe K E, Sullivan R J, Griffen D G, Sheehan L J. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty 1998; 13 (5): 530-4.

Kuklo T R, Potter B K, Polly D W, Jr., O'Brien M F, Schroeder T M, Lenke L G. Reliability analysis for manual adolescent idiopathic scoliosis measurements. Spine (Phila Pa 1976) 2005; 30 (4): 444-54.

Kummer F J, Shah S, Iyer S, DiCesare P E. The effect of acetabular cup orientations on limiting hip rotation. J Arthroplasty 1999; 14 (4): 509-13.

Laaksonen I, Donahue G S, Madanat R, Makela K T, Malchau H. Outcomes of the Recalled Articular Surface Replacement Metal-on-Metal Hip Implant System: A Systematic Review. J Arthroplasty 2017; 32 (1): 341-6.

Lafage V, Schwab F, Patel A, Hawkinson N, Farcy J P. Pelvic tilt and truncal inclination: Two key radiographic parameters in the setting of adults with spinal deformity. Spine 2009; 34 (17): E599-E606.

Lafage V, Schwab F, Skalli W, Hawkinson N, Gagey P M, Ondra S, et al. Standing balance and sagittal plane spinal deformity: analysis of spinopelvic and gravity line parameters. Spine (Phila Pa 1976) 2008; 33 (14): 1572-8.

Lainiala O, Elo P, Reito A, Pajamaki J, Puolakka T, Eskelinen A. Good sensitivity and specificity of ultrasound for detecting pseudotumors in 83 failed metal-on-metal hip replacements. Acta Orthop 2015; 86 (3): 339-44.

Lainiala O S, Moilanen T P S, Hart A J, Huhtala H S A, Sabah S A, Eskelinen A P. Higher Blood Cobalt and Chromium Levels in Patients With Unilateral Metal-on-Metal Total Hip Arthroplasties Compared to Hip Resurfacings. J Arthroplasty 2016; 31 (6): 1261-6.

Langton D J, Jameson S S, Joyce T J, Webb J, Nargol A V. The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. J Bone Joint Surg Br 2008; 90 (9): 1143-51.

Langton D J, Sprowson A P, Mahadeva D, Bhatnagar S, Holland J P, Nargol A V. Cup anteversion in hip resurfacing: validation of EBRA and the presentation of a simple clinical grading system. J Arthroplasty 2010; 25 (4): 607-13.

Lazennec J Y, Brusson A, Rousseau M A. Hip-spine relations and sagittal balance clinical consequences. Eur Spine J 2011; 20 Suppl 5: 686-98.

Lazennec J Y, Brusson A, Rousseau M A. Lumbar-pelvic-femoral balance on sitting and standing lateral radiographs. Orthop Traumatol Surg Res 2013; 99 (1 Suppl): S87-103.

Lazennec J Y, Rousseau M A, Rangel A, Gorin M, Belicourt C, Brusson A, et al. Pelvis and total hip arthroplasty acetabular component orientations in sitting and standing positions: Measurements reproductibility with EOS imaging system versus conventional radiographies. Orthopaedics and Traumatology: Surgery and Research 2011; 97 (4): 373-80.

Le Huec J C, Hasegawa K. Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. Eur Spine J 2016; 25 (11): 3630-7.

Legaye J. Influence of the sagittal balance of the spine on the anterior pelvic plane and on the acetabular orientation. International Orthopaedics 2009; 33 (6): 1695-700.

Legaye J, Duval-Beaupère G. Sagittal plane alignment of the spine and gravity a radiological and clinical evaluation. Acta Orthopaedica Belgica 2005; 71 (2): 213-20.

Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998; 7 (2): 99-103.

Lewinnek G E, Lewis J L, Tarr R, Compere C L, Zimmerman J R. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978; 60 (2): 217-20.

Lombardi A V, Jr., Barrack R L, Berend K R, Cuckler J M, Jacobs J J, Mont M A, et al. The Hip Society: algorithmic approach to diagnosis and management of metal-on-metal arthroplasty. J Bone Joint Surg Br 2012; 94 (11 Suppl A): 14-8.

Lombardi A V, Jr., Berend K R, Morris M J, Adams J B, Sneller M A. Large-diameter metal-on-metal total hip arthroplasty: dislocation infrequent but survivorship poor. Clin Orthop Relat Res 2015; 473 (2): 509-20.

Long W T, Dastane M, Harris M J, Wan Z, Dorr L D. Failure of the Durom Metasul acetabular component. Clin Orthop Relat Res 2010; 468 (2): 400-5.

Lu M, Zhou Y X, Du H, Zhang J, Liu J. Reliability and validity of measuring acetabular component orientation by plain anteroposterior radiographs. Clin Orthop Relat Res 2013; 471 (9): 2987-94.

Mac-Thiong J M, Berthonnaud E, Dimar J R, 2nd, Betz R R, Labelle H. Sagittal alignment of the spine and pelvis during growth. Spine (Phila Pa 1976) 2004; 29 (15): 1642-7.

Macpherson G J, Breusch S J. Metal-on-metal hip resurfacing: a critical review. Arch Orthop Trauma Surg 2011; 131 (1): 101-10.

Mahmood S S, Al-Amiry B, Mukka S S, Baea S, Sayed-Noor A S. Validity, reliability and reproducibility of plain radiographic measurements after total hip arthroplasty. Skeletal Radiol 2015; 44 (3): 345-51.

Maillot C, Ferrero E, Fort D, Heyberger C, Le Huec J C. Reproducibility and repeatability of a new computerized software for sagittal spinopelvic and scoliosis curvature radiologic measurements: Keops. Eur Spine J 2015; [Epub ehead of print].

Mangione P, Gomez D, Senegas J. Study of the course of the incidence angle during growth. Eur Spine J 1997; 6 (3): 163-7.

Masquefa T, Verdier N, Gille O, Boissière L, Obeid I, Maillot C, et al. Change in acetabular version after lumbar pedicle subtraction osteotomy to correct post-operative flat back: EOS® measurements of 38 acetabula. Revue de Chirurgie Orthopedique et Traumatologique 2015; 101 (6): 433-8.

Matthies A K, Henckel J, Cro S, Suarez A, Noble P C, Skinner J, et al. Predicting wear and blood metal ion levels in metal-on-metal hip resurfacing. J Orthop Res 2014; 32 (1): 167-74.

McArthur B, Cross M, Geatrakas C, Mayman D, Ghelman B. Measuring acetabular component version after THA: CT or plain radiograph? Clin Orthop Relat Res 2012; 470 (10): 2810-8.

McMinn D, Treacy R, Lin K, Pynsent P. Metal on metal surface replacement of the hip. Experience of the McMinn prothesis. Clin Orthop Relat Res 1996; (329 Suppl): S89-98.

Mehta V A, Amin A, Omeis I, Gokaslan Z L, Gottfried O N. Implications of spinopelvic alignment for the spine surgeon. Neurosurgery 2012; 70 (3): 707-21.

Mellon S J, Grammatopoulos G, Andersen M S, Pandit H G, Gill H S, Murray D W. Optimal acetabular component orientation estimated using edge-loading and impingement risk in patients with metal-on-metal hip resurfacing arthroplasty. J Biomech 2015; 48 (2): 318-23.

MHRA. Medicines and Healthcare products Regulatory Agency. 2012.Available from http://www.mhra.gov.uk/home/groups/dts-bs/documents/medicaldevicealert/con155767.pdf.

Mokka J. Bearing-spesific complications of total hip arthroplasty: characterization and treatment. University of Turku; 2015. Available from

Morel E, Ilharreborde B, Lenoir T, Hoffmann E, Vialle R, Rillardon L, et al. [Sagittal balance of the spine and degenerative spondylolisthesis]. Rev Chir Orthop Reparatrice Appar Mot 2005; 91 (7): 615-26.

Morris W Z, Fowers C A, Yuh R T, Gebhart J J, Salata M J, Liu R W. Decreasing pelvic incidence is associated with greater risk of cam morphology. Bone Joint Res 2016; 5 (9): 387-92.

Nho J H, Lee Y K, Kim H J, Ha Y C, Suh Y S, Koo K H. Reliability and validity of measuring version of the acetabular component. J Bone Joint Surg Br 2012; 94 (1): 32-6.

Nunley R M, Keeney J A, Zhu J, Clohisy J C, Barrack R L. The reliability and variation of acetabular component anteversion measurements from cross-table lateral radiographs. J Arthroplasty 2011; 26 (6 Suppl): 84-7.

Ochi H, Baba T, Homma Y, Matsumoto M, Nojiri H, Kaneko K. Importance of the spinopelvic factors on the pelvic inclination from standing to sitting before total hip arthroplasty. Eur Spine J 2016; 25 (11): 3699-706.

Ochi H, Homma Y, Baba T, Nojiri H, Matsumoto M, Kaneko K. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. Gait and Posture 2017; 52: 293-300.

Offierski C M, MacNab I. Hip-spine syndrome. Spine (Phila Pa 1976) 1983; 8 (3): 316-21.

Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gibbons C L, et al. Pseudotumours associated with metal-on-metal hip resurfacings. J Bone Joint Surg Br 2008; 90 (7): 847-51.

Parvizi J, Pour A E, Hillibrand A, Goldberg G, Sharkey P F, Rothman R H. Back pain and total hip arthroplasty: a prospective natural history study. Clin Orthop Relat Res 2010; 468 (5): 1325-30.

Patel S R, Toms A P, Rehman J M, Wimhurst J. A reliability study of measurement tools available on standard picture archiving and communication system workstations for the evaluation of hip radiographs following arthroplasty. J Bone Joint Surg Am 2011; 93 (18): 1712-9.

Philippot R, Wegrzyn J, Farizon F, Fessy M H. Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions. Orthopaedics and Traumatology: Surgery and Research 2009; 95 (1): 70-6.

Pierannunzii L. Pelvic posture and kinematics in femoroacetabular impingement: a systematic review. J Orthop Traumatol 2017.

Polly D W, Jr., Kilkelly F X, McHale K A, Asplund L M, Mulligan M, Chang A S. Measurement of lumbar lordosis. Evaluation of intraobserver, interobserver, and technique variability. Spine (Phila Pa 1976) 1996; 21 (13): 1530-5; discussion 5-6.

Pourtaheri S, Sharma A, Savage J, Kalfas I, Mroz T E, Benzel E, et al. Pelvic retroversion: a compensatory mechanism for lumbar stenosis. J Neurosurg Spine 2017; 27 (2): 137-44.

Qu X, Huang X, Dai K. Metal-on-metal or metal-on-polyethylene for total hip arthroplasty: a meta-analysis of prospective randomized studies. Arch Orthop Trauma Surg 2011; 131 (11): 1573-83.

Radcliff K E, Kepler C K, Hellman M, Restrepo C, Jung K A, Vaccaro A R, et al. Does spinal alignment influence acetabular orientation: a study of spinopelvic variables and sagittal acetabular version. Orthopaedic surgery 2014; 6 (1): 15-22.

Raphael I J, Kepler C K, Restrepo S, Radcliff K E, Rasouli M R, Albert T J. Pelvic incidence in patients with hip osteoarthritis. Archives of Bone and Joint Surgery 2016; 4 (2): 132-6.

Reito A, Eskelinen A, Puolakka T, Pajamaki J. Results of metal-on-metal hip resurfacing in patients 40 years old and younger. Arch Orthop Trauma Surg 2013; 133 (2): 267-73.

Reito A, Puolakka T, Paakkala A, Pajamaki J. Assessment of inter- and intra-observer reliability in the determination of radiographic version and inclination of the cup in metal-on-metal hip resurfacing. Int Orthop 2012; 36 (3): 519-25.

Ross J R, Nepple J J, Philippon M J, Kelly B T, Larson C M, Bedi A. Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. American Journal of Sports Medicine 2014; 42 (10): 2402-9.

Roussouly P, Berthonnaud E, Dimnet J. [Geometrical and mechanical analysis of lumbar lordosis in an asymptomatic population: proposed classification]. Rev Chir Orthop Reparatrice Appar Mot 2003; 89 (7): 632-9.

Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine (Phila Pa 1976) 2005; 30 (3): 346-53.

Roussouly P, Pinheiro-Franco J L. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J 2011; 20 Suppl 5: 609-18.

Roussouly P, Pinheiro-Franco J L. Sagittal parameters of the spine: biomechanical approach. Eur Spine J 2011; 20 Suppl 5: 578-85.

Sariali E, Lazennec J Y, Khiami F, Gorin M, Catonne Y. Modification of pelvic orientation after total hip replacement in primary osteoarthritis. HIP International 2009; 19 (3): 257-63.

Sato T, Nakashima Y, Matsushita A, Fujii M, Iwamoto Y. Effects of posterior pelvic tilt on anterior instability in total hip arthroplasty: a parametric experimental modeling evaluation. Clin Biomech (Bristol, Avon) 2013; 28 (2): 178-81.

Sautet P, Giorgi H, Chabrand P, Tropiano P, Argenson J N, Parratte S, et al. Is anatomic acetabular orientation related to pelvic morphology? CT analysis of 150 healthy pelvises. Orthop Traumatol Surg Res 2018; 104 (3): 347-51.

Savarino L, Cadossi M, Chiarello E, Fotia C, Greco M, Baldini N, et al. How do metal ion levels change over time in hip resurfacing patients? A cohort study. ScientificWorldJournal 2014; 2014: 7.

SAY. Suomen artroplastiayhdistys; 2012. Available from www.suomenartroplastiayhdistys.fi.

Schmalzried T P, Peters P C, Maurer B T, Bragdon C R, Harris W H. Long-duration metal-on-metal total hip arthroplasties with low wear of the articulating surfaces. J Arthroplasty 1996; 11 (3): 322-31.

Schonstrom N, Lindahl S, Willen J, Hansson T. Dynamic changes in the dimensions of the lumbar spinal canal: an experimental study in vitro. J Orthop Res 1989; 7 (1): 115-21.

Schwab F, Dubey A, Gamez L, El Fegoun A B, Hwang K, Pagala M, et al. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine (Phila Pa 1976) 2005; 30 (9): 1082-5.

Schwab F, Farcy J P, Bridwell K, Berven S, Glassman S, Harrast J, et al. A clinical impact classification of scoliosis in the adult. Spine (Phila Pa 1976) 2006; 31 (18): 2109-14.

Schwab F, Lafage V, Boyce R, Skalli W, Farcy J P. Gravity line analysis in adult volunteers: Age-related correlation with spinal parameters, pelvic parameters, and foot position. Spine 2006; 31 (25): E959-E67.

Schwab F, Lafage V, Patel A, Farcy J P. Sagittal plane considerations and the pelvis in the adult patient. Spine (Phila Pa 1976) 2009; 34 (17): 1828-33.

Seki M, Yuasa N, Ohkuni K. Analysis of optimal range of socket orientations in total hip arthroplasty with use of computer-aided design simulation. J Orthop Res 1998; 16 (4): 513-7.

Sidaginamale R P, Joyce T J, Lord J K, Jefferson R, Blain P G, Nargol A V, et al. Blood metal ion testing is an effectivescreening tool to identify poorly performing metal-on-metal bearingsurfaces. Bone Joint Res 2013; 2 (5): 84-95.

Siebenrock K A, Kalbermatten D F, Ganz R. Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. Clin Orthop Relat Res 2003; (407): 241-8.

Sing D C, Barry J J, Aguilar T U, Theologis A A, Patterson J T, Tay B K, et al. Prior lumbarspinal arthrodesis increases risk of prosthetic-related complication in total hip arthroplasty. J Arthroplasty 2016; 31 (9 Suppl): 227-32 e1.

Tang W M, Chiu K Y. Primary total hip arthroplasty in patients with ankylosing spondylitis. J Arthroplasty 2000; 15 (1): 52-8.

Tiziani S, Gautier L, Farei-Campagna J, Osterhoff G, Jentzsch T, Nguyen-Kim T D, et al. Correlation of pelvic incidence with radiographical parameters for acetabular retroversion: a retrospective radiological study. BMC Med Imaging 2015; 15: 39.

Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. Eur Spine J 2002; 11 (1): 80-7.

Vedantam R, Lenke L G, Bridwell K H, Linville D L, Blanke K. The effect of variation in arm position on sagittal spinal alignment. Spine (Phila Pa 1976) 2000; 25 (17): 2204-9.

Vedantam R, Lenke L G, Keeney J A, Bridwell K H. Comparison of standing sagittal spinal alignment in asymptomatic adolescents and adults. Spine (Phila Pa 1976) 1998; 23 (2): 211-5.

Vialle R, Ilharreborde B, Dauzac C, Guigui P. Intra and inter-observer reliability of determining degree of pelvic incidence in high-grade spondylolisthesis using a computer assisted method. Eur Spine J 2006; 15 (10): 1449-53.

Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. Journal of Bone & Joint Surgery, American Volume 2005; 87A (2): 260-7.

Vrtovec T, Janssen M M, Pernus F, Castelein R M, Viergever M A. Analysis of pelvic incidence from 3-dimensional images of a normal population. Spine (Phila Pa 1976) 2012; 37 (8): E479-85.

Wang Z, Wang B, Yin B, Liu W, Yang F, Lv G. The relationship between spinopelvic parameters and clinical symptoms of severe isthmic spondylolisthesis: A prospective study of 64 patients. European Spine Journal 2014; 23 (3): 560-8.

Weinberg D S, Gebhart J J, Liu R W, Salata M J. Radiographic Signs of Femoroacetabular Impingement Are Associated with Decreased Pelvic Incidence. Arthroscopy - Journal of Arthroscopic and Related Surgery 2016; 32 (5): 806-13.

Weinberg D S, Morris W Z, Gebhart J J, Liu R W. Pelvic incidence: an anatomic investigation of 880 cadaveric specimens. European Spine Journal 2016; 25 (11): 3589-95.

Weng W, Wu H, Wu M, Zhu Y, Qiu Y, Wang W. The effect of total hip arthroplasty on sagittal spinal–pelvic–leg alignment and low back pain in patients with severe hip osteoarthritis. European Spine Journal 2016; 25 (11): 3608-14.

Weng W J, Wang W J, Wu M D, Xu Z H, Xu L L, Qiu Y. Characteristics of sagittal spine–pelvis–leg alignment in patients with severe hip osteoarthritis. European Spine Journal 2015; 24 (6): 1228-36.

Wu W, Liang J, Du Y, Tan X, Xiang X, Wang W, et al. Reliability and reproducibility analysis of the Cobb angle and assessing sagittal plane by computer-assisted and manual measurement tools. BMC Musculoskeletal Disorders 2014; 15 (1).

Yang Y, Zuo J, Liu T, Xiao J, Liu S, Gao Z. Morphological Analysis of True Acetabulum in Hip Dysplasia (Crowe Classes I-IV) Via 3-D Implantation Simulation. J Bone Joint Surg Am 2017; 99 (17): e92.

York P J, Kim H J. Degenerative Scoliosis. Curr Rev Musculoskelet Med 2017; 10 (4): 547-58.

Yoshimoto H, Sato S, Masuda T, Kanno T, Shundo M, Hyakumachi T, et al. Spinopelvic alignment in patients with osteoarthrosis of the hip: A radiographic comparison to patients with low back pain. Spine 2005; 30 (14): 1650-7.

Yrjonen T. Prognosis in Perthes' disease after noncontainment treatment. 106 hips followed for 28-47 years. Acta Orthop Scand 1992; 63 (5): 523-6.

Zheng G Q, Zhang Y G, Chen J Y, Wang Y. Decision making regarding spinal osteotomy and total hip replacement for ankylosing spondylitis: experience with 28 patients. Bone Joint J 2014; 96-B (3): 360-5.

Zhu Z, Xu L, Zhu F, Jiang L, Wang Z, Liu Z, et al. Sagittal alignment of spine and pelvis in asymptomatic adults: norms in Chinese populations. Spine (Phila Pa 1976) 2014; 39 (1): E1-6.

Zilber S, Lazennec J Y, Gorin M, Saillant G. Variations of caudal, central, and cranial acetabular anteversion according to the tilt of the pelvis. Surg Radiol Anat 2004; 26 (6): 462-5

Original Publications

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Pernaa K, Seppänen M, Mäkelä K, Saltychev M.
Reliability of sagittal spinopelvic alignment measurements after total hip arthroplasty

Clinical Spine Surgery 2017; 30(7): E909–14

Reliability of Sagittal Spinopelvic Alignment Measurements After Total Hip Arthroplasty

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Study design: This is a observational study.

Objective: To evaluate the reliability of measuring sagittal spinopelvic alignment after hip arthroplasty.

Summary of Background Data: Pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and lumbar lordosis (LL) are widely used in planning the treatment of people with spinal and hip disorders. Previously, these measures have proved reliable when hip heads are intact. Thus far, it is not known whether they are also reliable after total hip replacement.

Materials and Methods: Two observers assessed PI, SS, PT, and LL in the radiographs of 97 patients who had undergone total hip replacement. Test-retest (intraobserver) and interobserver reliability were estimated.

Results: The intraclass correlation coefficient ranged from 0.92 to 0.97 and 0.85 to 0.94 for the intraobserver and interobserver settings, respectively, indicating an almost perfect correlation between observers or observations. The absolute intrarater measurement errors were 1.41 [95% confidence interval (CI), 0.98–2.03) for PI, 1.16 (95% CI, 0.78–1.74) for SS, 0.49 (95% CI, 0.31–0.76) for PT, and 1.75 (95% CI, 1.22–2.51) degrees for LL. The respective interrater figures were 2.82 (95% CI, 2.04–3.9), 2.44 (95% CI, 1.78–3.35), 0.73 (95% CI, 0.48–1.13), and 2.28 (95% CI, 1.55–3.34) degrees.

Conclusions: It seems that total hip arthroplasty does not affect the reliability of spinopelvic sagittal alignment measurements.

Level of evidence: Level II.

Key Words: pelvic incidence, pelvic tilt, sacral slope, lumbar lordosis, sagittal alignment, hip replacement, reliability

(*Clin Spine Surg* 2017;30:E909–E914)

Pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and lumbar lordosis (LL) are widely used as anatomic measures of sagittal spinopelvic alignment (Fig. 1). Previous studies have shown that sagittal spinopelvic alignment varies widely.[1,2] The shape and orientation of the pelvis and spine have been shown to be related.[3] PI is an individual, specific, and unchangeable measure that describes pelvic anatomy and LL independently of the position of the pelvis.[4,5] The SS and PT may change, and, therefore, they can be used as indicators of postural disorders. LL, which depicts the overall sagittal shape of the lumbar spine, is associated with the angles of the PI, PT, and SS.[3] Acetabular orientation seems to be dependent on the SS.[6] These sagittal measures have become increasingly important in determining the treatment and the prognosis of structural and degenerative spinal deformities.[7–9] It has been stated that these measures should be taken into consideration for every spinal patient as an indicator of possible sagittal spinopelvic imbalance.[10] It has also been suggested that these measures may be of help when making decision in hip surgery as well.[11,12] They may affect the planning and performance of a hip replacement, as well as play a role in predicting the outcome of surgery.

The measurement of sagittal spinopelvic alignment has been described in detail by Legaye et al[5] and found to be reliable.[13–17] Studies on repeated measurements of full-standing radiographs of an asymptomatic spine have suggested that both intraobserver and interobserver errors are similar regardless of the age group and the degree of spinal degeneration.[18,19] Previous studies on the reliability of these measurements have primarily been conducted among asymptomatic volunteers or patients who have had spinal disorders but intact femoral heads. Thus far no data exist on the measurement error that may occur between repeated measurements or observers in the assessment of spinopelvic imbalance after total hip arthroplasty.

The objective of this study was to evaluate both the intraobserver and interobserver reliabilities of measuring PI, SS, PT, and LL in standing lateral radiographs of the lumbar spine after hip arthroplasty.

MATERIALS AND METHODS

This study was a distinct part of an ongoing screening study among patients after large-diameter-head, metal-on-metal, total hip arthroplasty in a university orthopedic clinic.[20,21] The hospital ethics committee approved the study.

Data were collected on 101 consecutive patients who underwent large-diameter-head, metal-on-metal,

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total hip arthroplasty. Of the patients, 3 were excluded due to the absence of lumbar spine radiographs and 1 due to the low quality of the existing radiograph. The final sample included 54 male and 43 female patients with an average age of 68.7 (SD = 8.9) years. All of the images were taken between April 2014 and February 2015, an average of 50 (SD = 20.3) months after the arthroplasty. Of the patients, 90 underwent unilateral arthroplasty, and for 7 arthroplasty was bilateral. Altogether 17 of those who underwent the unilateral procedure had undergone some other type of hip replacement in the contralateral hip.

While standing straight and comfortably with the arms either crossed over the chest or resting on a horizontal stand, the patients had their lumbar spine and both hips x-rayed from the direction of right to left with the left side against the film cassette. All of the radiographs were independently assessed by 2 orthopedists (observer 1 and observer 2) using Carestream PACS imaging software (Carestream Health Inc., 2011. Version 11.3 turpacs. Onex Corp., Rochester, NY). Observer 1 performed measurements twice (approximately 2 mo between measurements), and observer 2 did so only once. Using the digital measuring tools included in the Carestream PACS software, the observers carried out all of the measurements as suggested by Legaye et al.[5]

PI was defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the center of the axis of the femoral heads (Fig. 1). SS was defined as the angle between the superior plate of the first sacral vertebra and a horizontal line. PT was defined as the angle between the line connecting the midpoint of the superior sacral plate to the axis of the femoral heads and the vertical axis. LL was measured as the angle between the superior endplates of the first lumbar and first sacral vertebrae using the Cobb technique. The center of the replaced hip was defined similarly with respect to the center of a nonoperated hip. The Carestream PACS imaging software finds the center of the prosthetic femoral head digitally after placing a circle around it. When the replaced hip covered the sight of the other hip, the center of the femoral head was defined as the center of the replaced hip.

Statistical Analysis

Difference and mean scores were calculated for each measurement pair. The 1-sample *t* test was used to compare the difference scores for each outcome variable: PI, SS, PT, and LL. The results were reported as 2-tailed *P*-values. A *P*-value of < 0.05 was considered statistically significant, referring to the systematic overestimation or underestimation of a measured angle. The 2-way random model intraclass correlation coefficient (ICC) was used to quantify the degree to which an observer's (intraobserver reliability) or 2 observers' (interobserver reliability) assessments resembled each other. The results were reported as single measures ICCs, describing how reliable it is to use only 1 observer, and as average measures ICCs, describing the reliability of agreement between 2 observers.

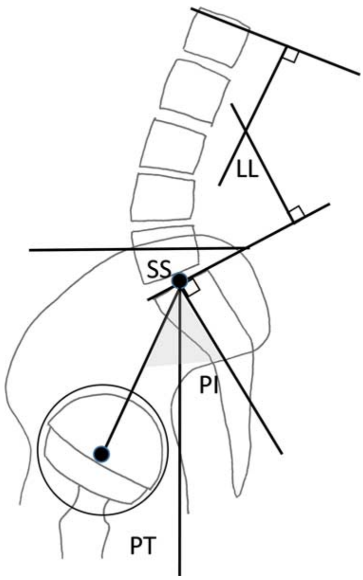

FIGURE 1. Measuring spinopelvic alignment and values of pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT) and lumbar lordosis (LL).

Cronbach α was also reported. Bland-Altman plots were constructed for each outcome variable. The difference between the 2 measurements per subject was plotted against the mean of the 2 measurements. As suggested previously for samples >60, 95% limits of agreement were calculated by using the following equation: 95% limit of agreement = mean $\pm$ $1.96\times$SD.[22] The linear regression model was used to detect the potential asymmetry of a plot—the proportional bias occurring when significantly more estimates are observed either above or below the mean line (reported as a 2-tailed *P*-value). The Spearman rank correlation coefficient was calculated for checking the agreement dependency of the mean of the 2 measurements—if the spread of the differences increases with an increasing mean of the observations. We were especially interested in obtaining the absolute error of the measurements regardless of the direction of the difference. Therefore, all of the difference estimates were transformed to positive by taking the square root of each squared difference estimate. Because of this transformation, more observations were grouped close to a zero difference, and the normal distribution became positively skewed. Thus the lognormal distribution was calculated using a decimal logarithm. The means and 95% confidence intervals were calculated for each outcome variable from the lognormal distribution and then back-transformed into degrees. We accepted that the

TABLE 1. Mean Scores and SDs for Pelvic Incidence, Sacral Slope, Pelvic Tilt, and Lumbar Lordosis

Assessments	Mean	SD
First assessment by observer 1		
Pelvic incidence	55.6	11.0
Sacral slope	38.6	9.5
Pelvic tilt	17.2	8.0
Lumbar lordosis	53.5	12.5
Second assessment by observer 1		
Pelvic incidence	54.7	11.0
Sacral slope	37.9	10.0
Pelvic tilt	17.2	8.1
Lumbar lordosis	53.7	14.0
Assessment by observer 2		
Pelvic incidence	51.9	11.3
Sacral slope	35.1	9.9
Pelvic tilt	16.6	8.8
Lumbar lordosis	50.8	14.9

95% confidence intervals became asymmetrical because of these steps. All of the calculations were made using IBM SPSS Statistics version 22 (IBM Corp. released 2013 IBM SPSS Statistics for Windows 64 bit, version 22.0; IBM Corp., Armonk, NY).

RESULTS

The average score for PI was 52–56 degrees. The scores for SS, PI, and LL averaged 35–39, 17, and 51–54 degrees, respectively (Table 1).

Intraobserver Reliability

For all 4 measures, the absolute error between 2 observations was less than 2 degrees. The mean difference was less than 1 degree with the limits of agreement varying between 2 to 4 degrees. For the PI and SS, a *P*-value of < 0.05 referred to the overestimation or underestimation of the measured angles when the first and second measurements were compared. For all 4 measures, both the single and average ICC measures showed a perfect correlation between the repeated measures, the estimates being 0.92–0.97, respectively. In the case of LL, there was a slight proportional bias with more estimates placed below the mean line than above it. For all 4 measures, the correlation between the mean difference and the average scores of each assessed pair was small and statistically nonsignificant (Table 2 and Fig. 2).

Interobserver Reliability

For PI, SS, and LL, the absolute error was <3 degrees. For PT, it was <1 degree. The mean difference varied between 3 and 4 degrees for PI, SS, and LL, and it was <1 degree for PT. For all 4 measures, the *P*-value of the *t* test was < 0.05 in reference to the overestimation or underestimation of the angles measured by 2 observers. For all 4 measures, both the single and average measures ICC showed a very strong correlation between the observations, the estimates ranging from 0.85 to 0.94. In the case of the PT and LL, there was a slight proportional bias with more estimates below the mean line than above it. For all 4 measures, the correlation between the mean

TABLE 2. Intraobserver and Interobserver Reliability of Measuring Pelvic Incidence (PI), Sacral Slope (SS), Pelvic Tilt (PT), and Lumbar Lordosis (LL)

	Intraobserver Reliability				Interobserver Reliability			
Statistics	PI	SS	PT	LL	PI	SS	PT	LL
Sample size	97	97	97	97	97	97	97	97
Error between observers or observations*								
Mean, degrees	1.41	1.16	0.49	1.75	2.82	2.44	0.73	2.28
Lower 95% confidence interval	0.98	0.78	0.31	1.22	2.04	1.78	0.48	1.55
Upper 95% confidence interval	2.03	1.74	0.76	2.51	3.9	3.35	1.13	3.34
Difference between observations or observers†								
Mean difference (deg.)	−0.89	−0.78	−0.08	0.16	−3.76	−3.55	−0.66	−2.71
SD (deg.)	3.60	3.79	2.08	4.10	4.98	4.22	2.94	5.83
Lower 95% limit of agreement	−7.94	−8.21	−4.16	−8.20	−13.52	−11.82	−6.42	−14.14
Higher 95% limit of agreement	6.17	6.65	4.00	7.88	6.00	4.72	5.10	9.72
1-sample *t* test, 2-tailed *P*	0.017	0.044	0.696	0.693	0.000	0.000	0.030	0.000
Test for proportional bias, 2-tailed *P*	0.930	0.175	0.712	0.000	0.571	0.291	0.013	0.040
Intraclass correlation coefficient (ICC)								
Single Measures ICC	0.94	0.92	0.97	0.95	0.85	0.85	0.94	0.88
Lower 95% confidence interval	0.92	0.89	0.95	0.93	0.57	0.49	0.91	0.81
Higher 95% confidence interval	0.97	0.95	0.98	0.97	0.93	0.94	0.96	0.94
Average Measures ICC	0.97	0.96	0.98	0.98	0.92	0.92	0.97	0.94
Lower 95% confidence interval	0.96	0.94	0.98	0.96	0.73	0.66	0.95	0.89
Higher 95% confidence interval	0.98	0.97	0.99	0.98	0.97	0.97	0.98	0.97
Cronbach α	0.97	0.96	0.98	0.98	0.95	0.95	0.97	0.95
Correlation between mean difference and average scores for each assessed pair								
Correlation coefficient (Spearman)	0.05	0.18	−0.03	0.02	0.06	0.03	0.25	0.33
2-tailed *P*	0.624	0.086	0.757	0.880	0.541	0.738	0.013	0.001

*Regardless of the direction of difference between observations.
†Distinguishing the direction of difference between observations.

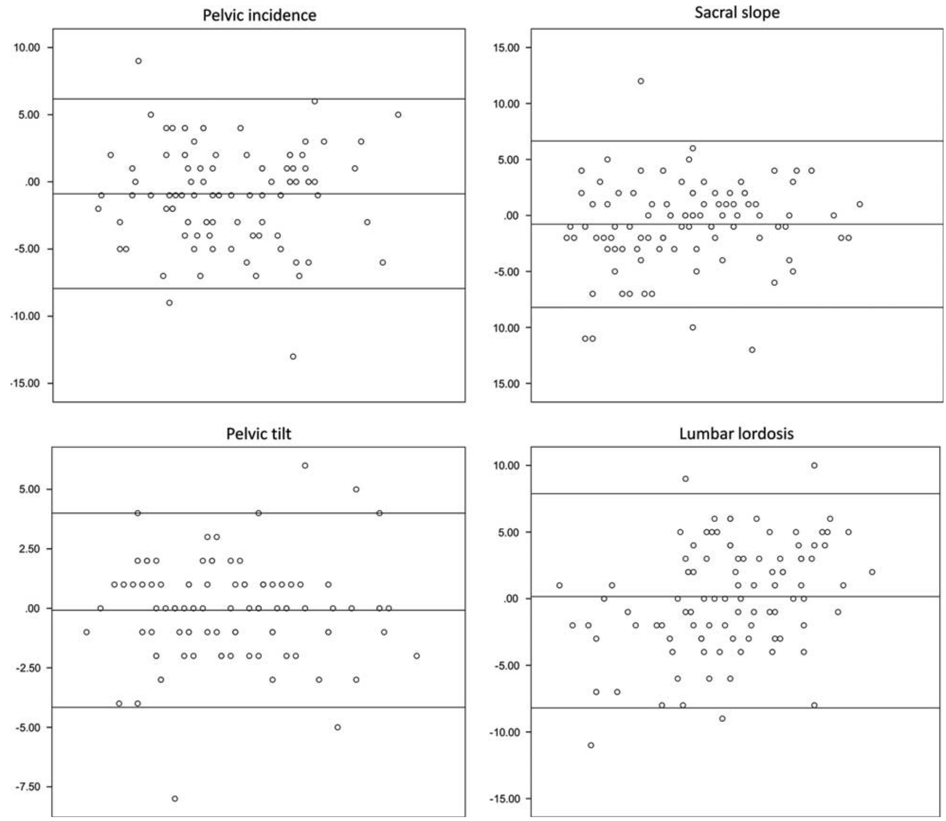

FIGURE 2. Bland-Altman plots of intraobserver reliability. Dots represent paired repeated measures obtained for 1 observer. The scores of difference between paired observations are placed on *y*-axis and mean values of each pair are located on the *x*-axis. The central line denotes the mean difference values. The upper and lower lines denote 95% limits of agreement.

difference and the average scores for each assessed pair was low, being statistically nonsignificant for PI and SS and significant for PT and LL (Table 2 and Fig. 3).

DISCUSSION

The assessment of 97 radiographs showed that PI, SS, PT, and LL can be reliably measured after hip replacement. Both the intraobserver and interobserver reliabilities were found to be high. For all 4 of the assessed measures, the intraobserver error was < 2 degrees, whereas the interobserver error ranged from 1 to 3 degrees.

As far as we know, this is the first study to report the reliability of measuring spinopelvic sagittal alignment after hip replacement, and a comprehensive set of appropriate statistical methods was used. The accuracy of the measurements was assured by the precise tools included in Carestream PACS (0.01 degree-error). The differences between manual and computer-assisted techniques in measurements of spinopelvic angles have been previously considered small, even though the computer-assisted techniques seemed to be more reliable than the manual ones.[23,24]

Some weaknesses may have affected the generalization of our findings. Previous studies have suggested that the position of the arms during imaging may affect sagittal alignment.[25,26] In our study, the position of the upper limbs was not standardized, even though the patients were asked to stand straight. This may have affected the degree of SS, PT, and LL, but hardly the degree of PI, as it is independent of the standing position or the position of the pelvis. The experience and skills of

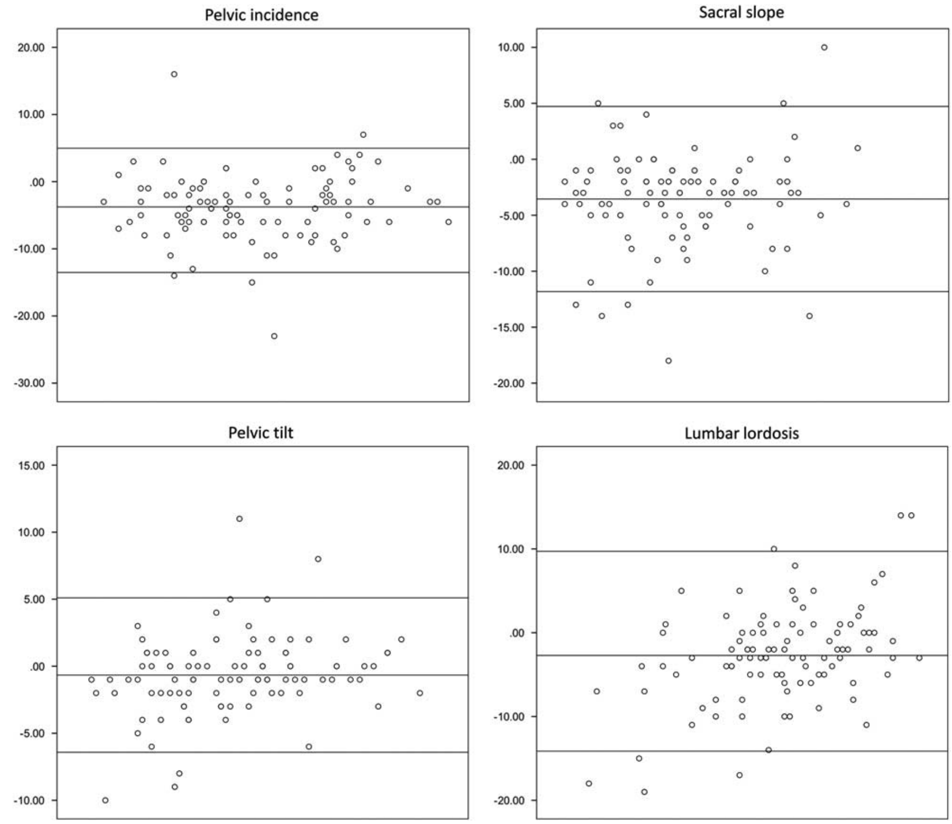

FIGURE 3. Bland-Altman plots of interobserver reliability. The dots represent paired measures obtained by separate observers. The scores of difference between paired observations are placed on the *y*-axis, and the mean values of each pair are located on the *x*-axis. The central line denotes the mean difference values. The upper and lower lines denote the 95% limits of agreement.

observers was not standardized. However, excellent interobserver reliability has been previously reported regardless the observers' skill level.[24,27] As shown in Figures 2 and 3, there were several outliers. We can only speculate on their real causes. Previous studies have suggested some sources of variability in the reliability of radiographic measurements of this kind, for example, a transitional vertebra or a variation in the architecture of an endplate.[28] A transitional vertebra may explain sporadic differences of >10 degrees in the measurements of PT observed by us. Another example is the unusual shape of the first sacral vertebral endplate due to isthmic spondylolysis or spondylolisthesis, which may also affect the precision of measurement. In this study, the most precise figures were obtained when PT was measured. This result may be explained by the fact that the variation in the architecture of a first sacral endplate may affect the degree of SS and LL, but not as much to the degree of PI or PT.

Finding the midpoints of femoral heads on radiographs is not necessary when SS and LL are being assessed. Instead, measuring PI and PT angles is based on identifying the midpoints of femoral heads and the center of the axis connecting them. In lateral spinal radiographs, the large diameter, metal-on-metal, total hip head may block out the sight of a nonoperated femoral head. It is also possible that the midpoint of the femoral head has somewhat changed due to arthroplasty. Therefore, the chance for measurement error may be greater with bilateral hip replacement. In addition, Kuklo et al[29] have reported a minor difference between the reliability of preoperative versus postoperative measurements of a 4th lumbar vertebra tilt and a Cobb angle. They have partially explained their finding by the overlying implants obscuring the endplate. Despite our suspicion that these concerns may have affected the reliability of the measurements in our sample, the reliability figures for all 4 measures were nearly equal, suggesting that the replacement of a femoral head probably does not weaken the reliability of sagittal measurements.

For the most part, our results support the findings of previous studies. Several studies have reported some interobserver and intraobserver variation in the assessment of spinopelvic measures. For example, Hwang et al[17] reported a SE of 2 degrees for measurements of LL. Polly et al[28] found that most repeated measures of LL are within 10 degrees. An error of 2–4 degrees has been reported by Vedantam et al[18] for the assessment of spinal sagittal alignment when PI and PT are not included in the assessment. Berthonnaud et al[27] have reported an interobserver error of <6 degrees for measurements of PI, SS, PT, and LL, finding, in accordance with our study, the lowest variability for PT. A very small interobserver and intraobserver error of <1 degree for PI has been reported by Vialle et al[14] for a series of 30 patients. In addition, in a recent study by Maillot et al,[24] the interobserver mean difference of the sagittal measurement has been minimal, 0.1 degrees, with limits of agreement of 7 degrees. Further research may reveal the reliability of other approaches to spinopelvic measurements after total hip anthroplasty, for example, when using computed tomography images instead of plain radiographs, and also the possible influence of side, type, and bilaterality of the anthroplasty.

We found that hip replacement does not decrease the reliability of measuring spinopelvic sagittal alignment. In this study sample, both the intraobserver and interobserver reliabilities were found to be excellent. Our findings support the use of such measurement as a reliable tool in both clinical practice and research also after hip replacement.

REFERENCES

1. Roussouly P, Gollogly S, Berthonnaud E, et al. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine*. 2005;30:346–353.
2. Vaz G, Roussouly P, Berthonnaud E, et al. Sagittal morphology and equilibrium of pelvis and spine. *Eur Spine J*. 2002;11:80–87.
3. Berthonnaud E, Dimnet J, Roussouly P, et al. Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. *J Spinal Disord Tech*. 2005;18:40–47.
4. Duval-Beaupere G, Schmidt C, Cosson P. A Barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. *Ann Biomed Eng*. 1992;20:451–462.
5. Legaye J, Duval-Beaupere G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J*. 1998;7:99–103.
6. Legaye J, Duval-Beaupere G, Barrau A, et al. Relationship between sacral pelvic incidence and acetabular orientation. *Hip Int*. 2011;21:87–97.
7. Wang Z, Wang B, Yin B, et al. The relationship between spinopelvic parameters and clinical symptoms of severe isthmic spondylolisthesis: a prospective study of 64 patients. *Eur Spine J*. 2014;23: 560–568.
8. Barrey C, Jund J, Noseda O, et al. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. *Eur Spine J*. 2007;16:1459–1467.
9. Chaleat-Valayer E, Mac-Thiong JM, Paquet J, et al. Sagittal spino-pelvic alignment in chronic low back pain. *Eur Spine J*. 2011; 20(suppl 5):634–640.
10. Lazennec JY, Brusson A, Rousseau MA. Hip-spine relations and sagittal balance clinical consequences. *Eur Spine J*. 2011;20(suppl 5):686–698.
11. Hellman M, Haughom B, Brown N, et al. Pelvic incidence and femoroacetabular impingement-a novel relationship. *Arthroscopy*. 2013;29:e196–e197.
12. Radcliff KE, Kepler CK, Hellman M, et al. Does spinal alignment influence acetabular orientation: a study of spinopelvic variables and sagittal acetabular version. *Orthop Surg*. 2014;6:15–22.
13. Vialle R, Levassor N, Rillardon L, et al. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am*. 2005;87A:260–267.
14. Vialle R, Ilharreborde B, Dauzac C, et al. Intra and inter-observer reliability of determining degree of pelvic incidence in high-grade spondylolisthesis using a computer assisted method. *Eur Spine J*. 2006;15:1449–1453.
15. Jackson RP, Peterson MD, McManus AC, et al. Compensatory spinopelvic balance over the hip axis and better reliability in measuring lordosis to the pelvic radius on standing lateral radiographs of adult volunteers and patients. *Spine*. 1998;23:1750–1767.
16. Jackson RP, Hales C. Congruent spinopelvic alignment on standing lateral radiographs of adult volunteers. *Spine*. 2000;25:2808–2815.
17. Hwang JH, Modi HN, Suh SW, et al. Reliability of lumbar lordosis measurement in patients with spondylolisthesis: a case-control study comparing the Cobb, centroid, and posterior tangent methods. *Spine*. 2010;35:1691–1700.
18. Vedantam R, Lenke LG, Keeney JA, et al. Comparison of standing sagittal spinal alignment in asymptomatic adolescents and adults. *Spine*. 1998;23:211–215.
19. Gelb DE, Lenke LG, Bridwell KH, et al. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine*. 1995;20:1351–1358.
20. Junnila M, Seppanen M, Mokka J, et al. Adverse reaction to metal debris after Birmingham hip resurfacing arthroplasty. *Acta Orthop*. 2015;13:1–6.
21. Mokka J, Junnila M, Seppanen M, et al. Adverse reaction to metal debris after ReCap-M2A-Magnum large-diameter-head metal-on-metal total hip arthroplasty. *Acta Orthop*. 2013;84:549–554.
22. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1: 307–310.
23. Wu W, Liang J, Du Y, et al. Reliability and reproducibility analysis of the Cobb angle and assessing sagittal plane by computer-assisted and manual measurement tools. *BMC Musculoskelet Disord*. 2014;15:33.
24. Maillot C, Ferrero E, Fort D, et al. Reproducibility and repeatability of a new computerized software for sagittal spinopelvic and scoliosis curvature radiologic measurements: Keops. *Eur Spine J*. 2015;24:1574–1581.
25. Horton WC, Brown CW, Bridwell KH, et al. Is there an optimal patient stance for obtaining a lateral 36" radiograph? A critical comparison of three techniques. *Spine*. 2005;30:427–433.
26. Vedantam R, Lenke LG, Bridwell KH, et al. The effect of variation in arm position on sagittal spinal alignment. *Spine*. 2000;25: 2204–2209.
27. Berthonnaud E, Labelle H, Roussouly P, et al. A variability study of computerized sagittal spinopelvic radiologic measurements of trunk balance. *J Spinal Disord Tech*. 2005;18:66–71.
28. Polly DW Jr, Kilkelly FX, McHale KA, et al. Measurement of lumbar lordosis. Evaluation of intraobserver, interobserver, and technique variability. *Spine*. 1996;21:1530–1535; discussion 5–6.
29. Kuklo TR, Potter BK, Polly DW Jr, et al. Reliability analysis for manual adolescent idiopathic scoliosis measurements. *Spine*. 2005;30:444–454.

Original Publications

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Pelvic incidence and hip disorders

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Pelvic incidence and hip disorders

A systematic review and quantitative analysis

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Background and purpose — The role of pelvic incidence in hip disorders is unclear. Therefore, we undertook a literature review to evaluate the evidence on that role.

Methods — A search was carried out on MEDLINE, SCOPUS, CENTRAL, and CINAHL databases. Quantitative analysis was based on comparison with a reference population of asymptomatic subjects.

Results — The search resulted in 326 records: 15 studies were analyzed qualitatively and 13 quantitatively. The estimates of pelvic incidence varied more than 10 degrees from 47 (SD 3.7) to 59 (SD 14). 2 studies concluded that higher pelvic incidence might contribute to the development of coxarthrosis while 1 study reported the opposite findings. In 2 studies, lower pelvic incidence was associated with a mixed type of femoroacetabular impingement. We formed a reference population from asymptomatic groups used or cited in the selected studies. The reference comprised 777 persons with pooled average pelvic incidence of 53 (SD 10) degrees. The estimate showed a relatively narrow 95% CI of 52 to 54 degrees. The 95% CIs of only 4 studies did not overlap the CIs of reference: 2 studies on coxarthrosis, 1 on mixed femoroacetabular impingement, and 1 on ankylosing spondylitis

Interpretation — We found no strong evidence that pelvic incidence plays any substantial role in hip disorders. Lower pelvic incidence may be associated with the mixed type of femoroacetabular impingement and hip problems amongst patients with ankylosing spondylitis. The evidence on association between pelvic incidence and coxarthrosis remained inconclusive.

Pelvic incidence is an individual and unchangeable measure that describes pelvic anatomy independently of the position of the pelvis (Duval-Beaupere et al. 1992, Legaye et al. 1998). It is defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the center of the axis of the femoral heads (Legaye et al. 1998) (Figure 1). The pelvic incidence becomes stabilized around the age of 10 years (Mangione et al. 1997) varying widely from 33 to 85 degrees (Vaz et al. 2002). For more than 30 years, it has been thought that pelvic incidence may be related to certain spinal disorders (Offierski and MacNab 1983, Barrey et al. 2007, Chaleat-Valayer et al. 2011, Wang et al. 2014) and, sometimes, both back pain and pelvic incidence have been described as altered after a hip replacement (Ben-Galim et al. 2007, Parvizi et al. 2010, Eyvazov et al. 2016).

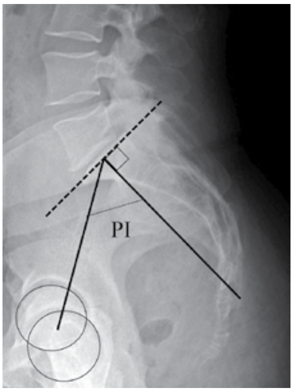

Figure 1. Measurement of pelvic incidence

The role of pelvic incidence in hip disorders has been studied less. There have been no comprehensive systematic reviews conducted on the topic so far. The reports on that role have been inconsistent, suggesting that either such a role does not exist (Weng et al. 2016, Ochi et al. 2017) or that higher pelvic incidence may predispose or be otherwise connected to coxarthrosis (Yoshimoto et al. 2005, Bredow et al. 2015,

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Ochi et al. 2017). The evidence has been controversial. It has been suggested that higher pelvic incidence might contribute to the development of hip osteoarthrosis, as individuals with increased pelvic incidence tend to lose the anterior covering of the acetabulum due to excessive pelvic tilt with aging (Yoshimoto et al. 2005). Additionally, hip osteoarthrosis may probably be triggered by damage to the cartilage or labrum caused by femoroacetabular impingement, which is related, in turn, to abnormal pelvic incidence (Beck et al. 2005). Gebhart et al. (2016) studied cadaveric specimens and reported a significant correlation between higher pelvic incidence and hip osteoarthrosis-while no such connection was found by Raphael et al. (2016) when analyzing computed tomography of patients with hip disorders. Even fewer studies have been conducted on the significance of pelvic incidence in hip pathologies other than coxarthrosis. It has been suggested that pelvic incidence may play some role in hip disorders associated with ankylosing spondylitis, femoroacetabular impingement (FAI), and subchondral insufficiency fractures (Gao et al. 2015, Gu et al. 2015, Jo et al. 2016, Hellman et al. 2017). In 2 recent systematic reviews (Pierannunzii 2017, Riviere et al. 2017) on femoroacetabular impingement (FAI), lower pelvic incidence has been suggested to relate to a mixed type of impingement. The correlation between anterior pelvic tilt and lower pelvic incidence and FAI occurrence has been considered so important that Riviere et al. (2017) even suggested a classification of spinopelvic parameters as risk factors of developing FAI.

The objective of this systematic review was to evaluate the evidence on the connection between pelvic incidence and hip disorders.

Methods

PICO

The criteria for considering studies for this review were based on the PICO (Population, Intervention, Comparison, and Outcome) framework as follows:

- Adults with hip disorders excluding malignancy and acute trauma. Observational and clinical studies published in peer-reviewed journals excluding theses, conference proceedings, and guidelines. No restrictions based on the time of publication or language. Abstract available.
- Intervention—not applicable.
- Comparison—not applicable.
- Outcome—primary: risk ratios or odds ratios; secondary—any outcome.

Data sources and searches

The Cochrane Controlled Trials Register (CENTRAL), MEDLINE (via PubMed), CINAHL, and SCOPUS databases were searched in February 2017. The search clauses are presented in Table 1 (see Supplementary data). The references of identified articles and reviews were also checked for relevancy.

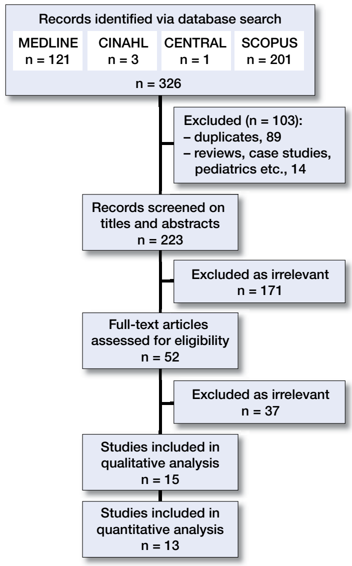

Figure 2. Search and data extraction flow. No additional records were identified from reference lists.

Study selection

2 independent reviewers screened titles and abstracts of articles and assessed full texts of potentially relevant studies (Figure 2). Disagreements between reviewers were resolved by consensus or by a third reviewer. The methodological quality of the included trials was not rated.

Data extraction

The ultimate goal of the review was to evaluate the available evidence on the topic quantitatively. Therefore, when extracting data, some records were omitted due to inability to provide the statistics needed for analysis or as being subsets of the same study. For example, a study was excluded if pelvic incidence average figures were not reported. The data needed for a quantitative analysis were extracted from the included trials using a standardized form based on recommendations by the Cochrane Handbook for Systematic Reviews of Interventions 5.1.0 Edition, part 7.6.9 (Higgins and Green 2011).

Statistics

When not reported, a standard deviation (SD) was calculated from a range as:

$$SD = (maximum - minimum) / 4$$

Pooled average estimates (M) of several studies were calculated without weighting the studies according to their variance. Pooled SDs of several studies were calculated as ("n"—sample size):

$$SD_{pooled} = \sqrt{[(n_1 - 1) \times SD_1^2 + (n_2 - 1) \times SD_2^2 + \ldots + (n_k - 1) \times SD_k^2) / (n_1 + n_2 + \ldots + n_k - k)]}$$

The 95% confidence intervals (95% CI) were calculated as:

$$95\%\ CI = Mean \pm 1.96 \times (SD/\sqrt{n})$$

All the calculations were made using Microsoft® Excel® 2013 (Microsoft Corp, Redmond, WA, USA). The study protocol is available on request from the corresponding author.

Funding and potential conflicts of interest

No funding was received and no conflicts of interest are declared.

Results

The search resulted in 326 records, of which 223 were screened based on their titles and abstracts, and 52 based on their full texts (Table 2, see Supplementary data and Figure 2). 15 studies were analyzed qualitatively in more detail. After excluding 2 studies, the final sample for the quantitative analysis comprised 13 studies (Table 3, see Supplementary data).

All of the 15 studies were published within the last 8 years. Most of the included studies were retrospective. 10 studies targeted patients with coxarthrosis, 2 studies—patients with ankylosing spondylitis, 2 studies—patients with femoroacetabular impingement (FAI), and 1 study was focused on subchondral insufficiency fractures. Reference groups were used in 7 studies: 6 reference samples were drawn out of a healthy population (of these, 1 sample was matched) and 1 control group consisted of patients with low back pain. Among the studies, 6 were cross-sectional while the rest assessed spinopelvic parameters before and after hip total replacement. Lateral standing radiography was used in all studies, except for 1 (Weinberg et al. 2016a). In addition, some of the included studies employed a 3D reconstruction technique, sitting radiography, computed tomography, and magnetic resonance imaging. The inclusion and exclusion criteria were considered appropriate and clearly defined in all studies except for one (Gu et al. 2015).

The sample sizes of the included studies varied from 19 to 150 patients (Table 3, see Supplementary data). As expected, the patients with coxarthrosis and subchondral insufficiency fractures were older (around 60 years or older) than patients with ankylosing spondylitis or femoroacetabular impingement (< 40 years). Across the samples, there was a slight predomination of women. The estimates of pelvic incidence varied more than 10 degrees from 47 (SD 4) to 59 (SD 14). The authors of a few studies concluded that pelvic incidence might play some role in hip disorders, even though the sample sizes were considered underpowered to detect statistically significant results.

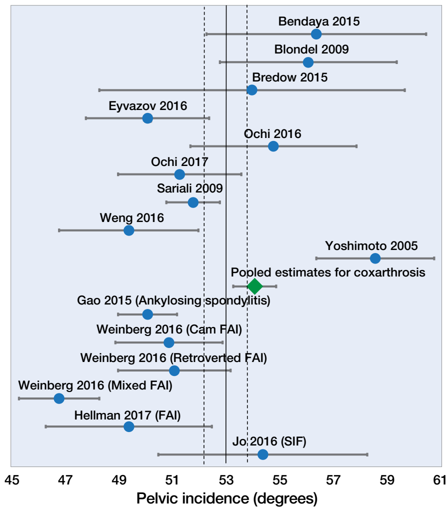

Figure 3. Forest plot of pelvic incidence estimates reported by the included studies and their pooled figures along with those for an asymptomatic population.Solid line delineates the pooled average estimate of pelvic incidence in an asymptomatic population. Dashed lines demarcate the 95% confidence interval of that estimate. Diamond shape represents the pooled estimate of pelvic incidence in patients with coxarthrosis. First-named author only cited.

2 studies concluded that higher pelvic incidence might contribute to the development of coxarthrosis (Yoshimoto et al. 2005, Bredow et al. 2015). Conversely, 1 study (Weng et al. 2015) reported that pelvic incidence might not be involved in coxarthrosis. Gao et al. (2015) reported that pelvic incidence might be correlated with life quality, body pain, "vitality," and "emotional role" in patients with ankylosing spondylitis when comparing the data gathered before and after hip replacement. Hellman et al. (2017) stated that pelvic incidence in patients with femoroacetabular impingement was lower than in the general population—49 (SD 12) versus 55 (SD 11), respectively. Weinberg et al. (2016a) specified further that this effect only exists in the Cam type of femoroacetabular impingement.

To form a reference population of asymptomatic individuals for this review, "healthy" groups used in the included studies along with the reports cited by them were pooled (Legaye et al. 1998, Roussouly et al. 2005, Vialle et al. 2005, Legaye 2009, Sariali et al. 2009, Weng et al. 2015, Jo et al. 2016, Weinberg et al. 2016a). In this way, the reference "healthy" sample comprised 777 persons (Table 4, see Supplementary data, and Figure 3). Their sex was equally distributed and they were younger (39 (SD 11) years) than their symptomatic counterparts, except for the studies on ankylosing spondylitis and femoroacetabular impingement. Within this asymptomatic group, the pooled average estimate of pelvic incidence was 53 (SD 10) degrees. The estimate showed a relatively narrow 95% CI of 52 to 54 degrees. For the subpopulation of patients with coxarthrosis (pooled n = 602 subjects), the pooled mean estimate of pelvic incidence was 54 (SD 11) degrees with 95% CI 53 to 55 degrees overlapping the 95% CI of the estimate pooled from an asymptomatic population. Figure 3 presents these findings in the form of a forest plot. From this figure, it can be noticed that CIs of only 4 studies did not overlap the 95% CI calculated for an asymptomatic population: 2 studies on coxarthrosis (Yoshimoto et al. 2005, Weng et al. 2015), 1 on mixed femoroacetabular impingement (Weinberg et al. 2016a), and 1 on ankylosing spondylitis (Gao et al. 2015).

Discussion

This systematic review did not find evidence that pelvic incidence would play any substantial role in hip disorders. However, the results suggested that lower pelvic incidence might be associated with femoroacetabular impingement (at least its mixed type) and with hip problems associated with ankylosing spondylitis. The evidence on association between pelvic incidence and coxarthrosis remained inconclusive.

The main weakness of this review lies in the weaknesses and the scope of the included studies. Most of the studies were retrospective and underpowered. Only a few studies focused on pelvic incidence as a main target. For the rest, pelvic incidence was only a secondary outcome or part of spinopelvic sagittal alignment totality. The study designs, reference groups, settings, and methods varied widely, leading to incapability to perform a true meta-analysis or to analyze systematically the methodological quality of the studies. We did not conduct a meta-synthesis and therefore the degree of heterogeneity between the included trials remains unknown. Our quantitative analysis should be generalized with caution—rather as an uncertain predisposition than as an exact recommendation. Despite these weaknesses, this systematic review provides valuable knowledge on the topic of interest both qualitatively and quantitatively. The results should be noted when screening for the risk factors of hip disorders, planning surgery, or predicting the course of these conditions.

This is the first systematic review focused entirely on the importance of only one single spinopelvic parameter—pelvic incidence—amongst patients with different hip problems. Therefore, the results are not directly comparable with any previous reports. The diversity and inconsistency of evidence on the topic may reflect the fact that, while the significance of pelvic incidence in different disorders has been proposed for 3 decades, most research on the subject is just beginning. Indeed, 12 of 15 included studies have been conducted very recently, in a narrow 2-year timeframe. Thus, one might expect more data on the matter to appear in the few next years, which may soon require a review update.

The interpretation of the results is especially difficult as there is no agreement on "normal" reference values for pelvic incidence (Vaz et al. 2002). It has even been suggested that such values may not be settable as there is also a high variance of pelvic incidence estimates amongst healthy subjects (Vrtovec et al. 2012). However, this doubt is not in line with probably the largest report on pelvic incidence measurement conducted on 880 cadaveric specimens (Weinberg et al. 2016b), which showed no barrier to creating reference values of pelvic incidence. Nevertheless, reference values are so far waiting to be created in a large population-based study on the topic.

According to this review, of all existing hip disorders, only 4 had been studied regarding the topic so far. As most included studies were conducted amongst patients with coxarthrosis, many questions are left for research. For example, the association between pelvic incidence and osteoporotic or other fractures in spinopelvic area is unclear.

The scope of this review was limited only to pelvic incidence. Pelvic posture and kinematics connected to spinal balance might play a more relevant role in hip disorders than pelvic incidence. There might be a connection between femoroacetabular impingement and low pelvic incidence. The pathogenesis and the exact definition of the mixed type of femoroacetabular impingement are unclear and femoroacetabular impingement often demonstrates anatomical features of both cam and pincer types (Ganz et al. 2003, 2008). This fact adds uncertainty concerning the association between the mixed type of femoroacetabular impingement and pelvic incidence.

In summary, we found no evidence that pelvic incidence plays any substantial role in hip disorders. Lower pelvic incidence may be associated with the mixed type of femoroacetabular impingement and hip problems amongst patients with ankylosing spondylitis. The evidence on association between pelvic incidence and coxarthrosis remained inconclusive.

Supplementary data

Tables 1–4 are available as supplementary data in the online version of this article, http://dx.doi.org/ 10.1080/17453674.2017.1377017

Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis–spine complex and lumbar degenerative diseases: A comparative study about 85 cases. Eur Spine J 2007 16 (9): 1459-67.

Beck M, Kalhor M, Leunig M, R Ganz. Hip morphology influences the pattern of damage to the acetabular cartilage: Femoroacetabular impingement as a cause of early osteoarthritis of the hip. J Bone Joint Surg Br 2005; 87 (7): 1012-18.

Ben-Galim P, Ben-Galim T, Rand N, Haim A, Hipp J, Dekel S, Floman Y. Hip–spine syndrome: The effect of total hip replacement surgery on low back pain in severe osteoarthritis of the hip. Spine (Phila Pa 1976) 2007; 32 (19): 2099-102.

Bendaya S, Lazennec J Y, Anglin C, Allena R, Sellam N, Thoumie P, Skalli W. Healthy vs. osteoarthritic hips: A comparison of hip, pelvis and femoral parameters and relationships using the EOS® system. Clin Biomech 2015; 30 (2): 195-204.

Blondel B, Parratte S, Tropiano P, Pauly V, Aubaniac J M, Argenson J N. Pelvic tilt measurement before and after total hip arthroplasty. Orthop Traumatol Surg Res 2009; 95 (8): 568-72.

Bredow J, Katinakis F, Schlüter-Brust K, Krug B, Pfau D, Eysel P, Dargel J, Wegmann K. Influence of hip replacement on sagittal alignment of the lumbar spine: An EOS study. Technology and Health Care 2015; 23 (6): 847-54.

Chaleat-Valayer E, Mac-Thiong J M, Paquet J, Berthonnaud E, Siani F, Roussouly P. Sagittal spino-pelvic alignment in chronic low back pain. Eur Spine J 2011; 20 (Suppl 5): 634-40.

Duval-Beaupere G, Schmidt C, Cosson P A. Barycentremetric study of the sagittal shape of spine and pelvis: The conditions required for an economic standing position Ann Biomed Eng 1992; 20 (4): 451-62.

Eyvazov K, Eyvazov B, Basar S, Nasto L A, Kanatli U. Effects of total hip arthroplasty on spinal sagittal alignment and static balance: A prospective study on 28 patients. European Spine J 2016; 25 (11): 3615-21.

Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock K A. Femoroacetabular impingement: A cause for osteoarthritis of the hip. Clin Orthop Relat Res 2003; (417): 112-20.

Ganz R, Leunig M, Leunig-Ganz K, Harris W H. The etiology of osteoarthritis of the hip: An integrated mechanical concept. Clin Orthop Relat Res 2008; 466 (2): 264-72.

Gao Y, Wang B, Xie Z K, Shen P F, Xu J D, Zheng C, Qu Y X. Total hip arthroplasty for ankylosing spondylitis: The spine-pelvis sagittal balance and quality of life. Chinese Journal of Tissue Engineering Research 2015; 19 (4): 516-21.

Gebhart J J, Weinberg D S, Bohl M S, Liu R W. Relationship between pelvic incidence and osteoarthritis of the hip. Bone Joint Res 2016; 5 (2): 66-72.

Gu M, Zhang Z, Kang Y, Sheng P, Yang Z, Zhang Z, Liao W. Roles of sagittal anatomical parameters of the pelvis in primary total hip replacement for patients with ankylosing spondylitis. J Arthroplasty 2015; 30 (12): 2219-23.

Hellman M D, Haughom B D, Brown N M, Fillingham Y A, Philippon M J, Nho S J. Femoroacetabular impingement and pelvic incidence: Radiographic comparison to an asymptomatic control. Arthroscopy 2017; 33(3): 545-50.

Higgins J, Green S. Cochrane Handbook for Systematic Reviews of Interventions, Version 510 [updated March 2011]. 2011. http://training.cochrane.org/handbook

Jo W L, Lee W S, Chae D S, Yang I H, Lee K M, Koo K H. Decreased lumbar lordosis and deficient acetabular coverage are risk factors for subchondral insufficiency fracture. J Korean Medical Science 2016; 31 (10): 1650-5.

Legaye J. Influence of the sagittal balance of the spine on the anterior pelvic plane and on the acetabular orientation. Int Orthop 2009; 33 (6): 1695-1700.

Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998; 7 (2): 99-103.

Mangione P, Gomez D, Senegas J. Study of the course of the incidence angle during growth. Eur Spine J 1997; 6 (3): 163-7.

Ochi H, Baba T, Homma Y, Matsumoto M, Nojiri H, Kaneko K. Importance of the spinopelvic factors on the pelvic inclination from standing to sitting before total hip arthroplasty. Eur Spine J 2016; 25 (11): 3699-706.

Ochi H, Homma Y, Baba T, Nojiri H, Matsumoto M , Kaneko K. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. Gait Posture 2017; 52: 293-300.

Offierski C M, MacNab I. Hip-spine syndrome. Spine (Phila Pa 1976) 1983; 8 (3): 316-21.

Parvizi J, Pour A E, Hillibrand A, Goldberg G, Sharkey P F, Rothman R H. Back pain and total hip arthroplasty: A prospective natural history study. Clin Orthop Relat Res 2010; 468 (5): 1325-30.

Pierannunzii L. Pelvic posture and kinematics in femoroacetabular impingement: A systematic review. J Orthop Traumatol 2017 [Epub ahead of print].

Raphael I J, Kepler C K, Restrepo S, Radcliff K E, Rasouli M R, Albert T J. Pelvic incidence in patients with hip osteoarthritis. Arch Bone Joint Surg 2016; 4 (2): 132-6.

Riviere C, Hardijzer A, Lazennec J Y, Beaule P, Muirhead-Allwood S, Cobb J. Spine-hip relations add understandings to the pathophysiology of femoroacetabular impingement: A systematic review. Orthop Traumatol Surg Res 2017; 103(4): 549-57.

Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine (Phila Pa 1976) 2005; 30 (3): 346-53.

Sariali E, Lazennec J Y, Khiami F, Gorin M, Catonne Y. Modification of pelvic orientation after total hip replacement in primary osteoarthritis. Hip International 2009; 19 (3): 257-63.

Wang Z, Wang B, Yin B, Liu W, Yang F, Lv G. The relationship between spinopelvic parameters and clinical symptoms of severe isthmic spondylolisthesis: A prospective study of 64 patients. Eur Spine J 2014; 23 (3): 560-8.

Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. Eur Spine J 2002; 11 (1): 80-7.

Weinberg D S, Gebhart J J, Liu R W, Salata M J. Radiographic signs of femoroacetabular impingement are associated with decreased pelvic incidence arthroscopy. J Arthroscopic and Related Surgery 2016a; 32 (5): 806-13.

Weinberg D S, Morris W Z, Gebhart J J, Liu R W. Pelvic incidence: An anatomic investigation of 880 cadaveric specimens. Eur Spine J 2016b; 25 (11): 3589-95.

Weng W J, Wang W J, Wu M D, Xu Z H, Xu L L, Qiu Y. Characteristics of sagittal spine-pelvis-leg alignment in patients with severe hip osteoarthritis. Eur Spine J 2015; 24 (6): 1228-36.

Weng W, Wu H, Wu M, Zhu Y, Qiu Y, Wang W. The effect of total hip arthroplasty on sagittal spinal-pelvic-leg alignment and low back pain in patients with severe hip osteoarthritis. Eur Spine J 2016; 25 (11): 3608-14.

Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Joint Surg Am 2005; 87 (2): 260-7.

Vrtovec T, Janssen M M, Pernus F, Castelein R M, Viergever M A. Analysis of pelvic incidence from 3-dimensional images of a normal population. Spine (Phila Pa 1976) 2012; 37 (8): E479-85.

Yoshimoto H, Sato S, Masuda T, Kanno T, Shundo M, Hyakumachi T, Yanagibashi Y. Spinopelvic alignment in patients with osteoarthrosis of the hip: A radiographic comparison to patients with low back pain. Spine 2005; 30 (14): 1650-7.

Original Publications

Pernaa K, Saltychev M, Mäkelä K.

Relationship between pelvic incidence angle and blood concentration of chromium and cobalt ions after metal-on-metal hip replacement: a brief report

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III

Original Research Article

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RELATIONSHIP BETWEEN PELVIC INCIDENCE ANGLE AND BLOOD CONCENTRATION OF CHROMIUM AND COBALT IONS AFTER METAL-ON-METAL HIP REPLACEMENT: A BRIEF REPORT

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ABSTRACT

Background and Aims: **The wear of metal-on-metal hip implants may increase chromium or cobalt ion blood level. This phenomenon may depend among other things on the particularity of spinopelvic anatomy. The effect of pelvic incidence angle on the wear of metal-on-metal hip implants is not known. The objective of the study was to investigate whether such effect does exist.**

Material and Methods: **The pelvic incidence and inclination of acetabular component angles of 89 patients after unilateral metal-on-metal hip replacement were compared with blood level of chromium and cobalt ions using Pearson correlation coefficient.**

Results: **No significant correlations between pelvic incidence angle and the metal ion blood levels were observed. The correlation coefficients varied from −0.02 to 0.2 and all p values were >0.05.**

Conclusion: **No evidence was found on the effect of pelvic incidence angle on metal wear after metal-on-metal hip replacement when measured by the blood levels of chromium and cobalt ions. It is reasonable to assume that other factors than pelvic tilt may affect the rate of implant wear.**

Key words: Pelvic incidence; metal ion; wear; hip arthroplasty; inclination; acetabular component

INTRODUCTION

Elevated chrome (Cr) and cobalt (Co) ion blood concentration may serve as a marker for the metal-on-metal (MoM) hip implants wear (1, 2). Currently, MoM bearing surfaces are not suggested to be used in hip surgery due to the metal wear and adverse reactions to metal debris (3). The connection between metal ion concentrations and the rate of implant wear offers an opportunity for investigating implant wear indirectly.

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Fig. 1. Measuring the value of pelvic incidence (PI).

This may provide an opportunity to measure quantitatively the links between wear rate and the different potential sources of wear.

Pelvic incidence (PI) (Fig. 1) is a measure describing pelvic anatomy and lumbar lordosis independent of the position of pelvis (4). Varying widely from 33 to 85°, PI affects the capacity of rotation of pelvis around femoral heads (5). While small PI angle limits the capacity to backward pelvic tilt, increased PI angle enlarges it (6). Pelvic tilt, determined by PI angle defines, in turn, the entire sagittal spinopelvic balance (4). Previous research has well established the important role of measuring adequate anteversion and lateral opening of the prosthesis acetabular component (7). The correct position of implant enhances clinical success, joint stability, good range of motion, and the absence of impingement (7, 8). It has been found that non-optimal implant position may contribute to the development of hip impingement and the increased wear of polyethylene liner or MoM bearings (2, 9).

Previously, it has been stated that there may be a correlation between PI, pelvic tilt, and acetabular orientation (10, 11). Additionally, high PI may cause the wider sagittal range of motion of total hip prosthesis and increased change of acetabular orientation when the patient moves (12). The relation between acetabular orientation and wear rates has previously been reported (2, 13). It is not known whether PI angle has any significant effect on pelvic and acetabular position, as well as on the range of movement of the prosthesis, and whether it is significant enough to cause the observable wear of hip prosthesis.

The objective was to investigate whether there is any correlation between the markers of MoM wear—Cr and Co ion blood levels—and PI angle. If such relationship exists, then PI measure might play an important role in positioning the acetabular component.

MATERIAL AND METHODS

Data were collected on the consecutive patients who underwent unilateral ReCap Magnum/Bimetric large-diameter head MoM total hip replacement (THR) or ReCap resurfacing arthroplasty (Biomet, Warsaw, IN, USA) in a university orthopedic clinic (3) during 2007–2011. Of the 93 eligible patients, 3 were excluded due to the absence of lumbar spine radiograph and 1 was excluded due to the absence of blood test results. The final sample included 48 male and 41 female patients with age on average 65.4 (standard deviation (SD) = 8.5) years. Of the 89 patients, 3 had a MoM resurfacing and 86 had a MoM THR. Additionally to MoM, 15 patients had earlier been exposed to other types of hip replacement on the contralateral side. All the radiographs and blood tests were taken between April 2014 and February 2015. The radiography for PI measurement was done while standing straight and comfortably with the arms either crossed over the chest or resting on a horizontal stand. The patients had their lumbar spine and both hips radiographed from the direction of right to left with the left side against the film cassette. PI was defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the center of the axis of the femoral heads (Fig. 1). PI was measured by an orthopedic surgeon as suggested by Legaye et al. (4). The center of the replaced hip was marked similar to the marking of the center of a non-operated hip. When the replaced hip covered the sight of the other hip, the center of the femoral head was defined as the center of the replaced hip. The inclination of acetabular component was assessed from pelvis anteroposterior radiographs by a radiologist. Acetabular component inclination of 30–50° has earlier been considered optimal (7). All the radiographic measurements were done using Carestream PACS® imaging software (Version 11.3 turpacs, 2011; Carestream Health, Inc. (Onex Corp.), Rochester, NY, USA). The hospital ethics committee approved the study.

STATISTICAL ANALYSIS

We ran a Shapiro–Wilk test for data normality appropriate for dataset smaller than 2000 elements. Therefore, to constructing a regression curve, abnormally distributed data were transformed into lognormal form. The estimates from normally distributed data were reported as means, SDs, and ranges. Otherwise, the results were reported as medians and ranges. Pearson correlation coefficient was used along with two-tailed p values (level of significance set at ≤ 0.05). Correlation ≥ 0.70 was considered very strong, 0.40–0.69 strong, 0.30–0.39 moderate, 0.20–0.29 weak, and 0.01–0.19 no or negligible correlation. All the calculations were made using IBM® SPSS® Statistics version 22 (Released 2013; IBM SPSS Statistics for Windows 64 bit, Version 22.0; IBM® Corp., Armonk, NY, USA).

RESULTS

The two-tailed p values were 0.148 for PI, for inclination 0.857, and <0.001 for chrome and cobalt blood contents, respectively. We concluded that the PI and

TABLE 1

Correlation (Pearson r) between metal ion blood levels and pelvic incidence and inclination of implant acetabular component, length of follow-up, and gender.

Measurement	Chrome ion blood concentration		Cobalt ion blood concentration	
	Correlation coefficient	p value	Correlation coefficient	p value
Pelvic incidence angle	–0.02	0.855	0.01	0.929
Inclination angle	–0.077	0.474	0.036	0.739
Time from surgery to test	–0.031	0.774	0.121	0.260
Gender	0.175	0.10	0.203	0.057

inclination data came from a normal distribution and the chrome and cobalt content data were abnormal. Therefore, to constructing a regression curve, chrome and cobalt data were transformed into lognormal form. Time between surgery and imaging and between surgery and blood test were also abnormal with Shapiro–Wilk test p values <0.001.

No dislocations had occurred and none of the patients needed a revision surgery for any other complication of arthroplasty. The time between operation and imaging and between operation and blood test was on median 41.6 (range 32–101) months.

The mean angle for PI was 55.8° (SD = 11.2°, range = 35°–83°). The respective figures for inclination of acetabular component were 41.5° (SD = 7.4°, range = 22°–60°). The Cr ion blood level was on median 1.6 (range = 0.7–13.6) µg/L. The respective median value for Co ion blood concentration was 1.5 (range = 0.4–29.6) µg/L. No significant correlations between PI or inclination angles and Cr or Co ion blood levels were observed (Table 1). There were also no correlations between metal ion blood levels and length of follow-up and/or gender. The correlation coefficients varied from –0.02 to 0.2 and all p values were >0.05.

DISCUSSION

In this prospective observational study of 89 patients who underwent a MoM hip replacement, correlations between PI or inclination angles and Cr or Co ion blood levels were small ≤0.2 and statistically insignificant. There were also no correlations between metal ion blood levels and length of follow-up and/or gender.

The Cr and Co ion blood levels have been proposed to be a reliable indicator of hip implants' wear (1, 14). Additionally to pelvic tilt, factors such as trunnion–head interface and passive corrosion or the stem surface or high inclination may affect the rate of wear (1, 2, 13, 15). Matthies et al. (16) reported that acetabular orientation explains less than 30% of variation in metal ion levels, while the rest might be explained by other factors such as component size and design. Langton et al. (13) also reported the smaller component size to effect the metal ion concentration.

In line with earlier studies reporting stability of metal ion levels up to 9 years after MoM hip resurfacing operation, no correlation was found between the metal ion blood levels and length of follow-up (17). Both hip resurfacing and THRs were included in the present sample. However, the amount of resurfacings was small, only three cases. Furthermore, resurfacings and MoM THRs included were analogous models from the same manufacturer. No significant difference in metal ion levels between hip resurfacings and different types of MoM THRs overall has previously been stated (18). However, when comparing blood metal ion levels between ASR resurfacing and ASR THR (DePuy Orthopaedics, Warsaaw, IN, USA), higher ion levels in patients with the ASR THR compared to ASR resurfacing have been reported (19). Of the patients, 15 had also exposed to metal-on-polyethylene replacement of contralateral hip. It is, though, unlikely that this could significantly affect the results as no increase in metal ion levels after metal-on-polyethylene hip replacement has previously been found (20).

Two-dimensional imaging used in this study might miscalculate the true three-dimensional acetabular component orientation and particularly the anteversion. Acetabular component may be well positioned with relation to inclination but not in relation to ante- or retroversion. This way, the lack of anteversion assessment in this study may affect the results. The range of the inclination of the acetabular component in this study was relatively wide that, in theory, may increase the wear of MoM bearings. However, it has previously been stated that inclination angle is not associated with adverse reaction to metal debris when using ReCap Magnum THR (21). Even though, increased femoral head size of ASR THR is a known risk factor for adverse reaction to metal debris (22), no reports have been published on the association between increased femoral head size of ReCap Magnum THR and increased blood metal ion levels. Therefore, measuring femoral head size was out of scope of this study.

A sample of less than 90 patients may be insufficient to achieve significant results when recognizing such weak correlations between PI and hip implant wear. Further research on larger sample size and longer follow-ups may reveal whether there is a weak correlation. As being potentially relevant, gender, inclination, and follow-up might be included in a multivariate model. Plain correlations may be insufficient to make any definitive conclusions since relevant risk factors may affect one another.

CONCLUSION

No evidence was found on the effect of PI angle on metal wear after MoM hip replacement when measured by the blood levels of chromium and cobalt ions.

APPROVAL OF INSTITUTIONAL REVIEW BOARD

This study was approved by Research Ethics Committee of the University of Turku (License ETMK 78/2013).

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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REFERENCES

1. De Smet K, De Haan R, Calistri A et al: Metal ion measurement as a diagnostic tool to identify problems with metal-on-metal hip resurfacing. J Bone Joint Surg Am 2008;90(Suppl. 4):202–208.
2. De Haan R, Pattyn C, Gill HS et al: Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. J Bone Joint Surg Br 2008;90(10):1291–1297.
3. Mokka J, Junnila M, Seppanen M et al: Adverse reaction to metal debris after ReCap-M2A-Magnum large-diameter-head metal-on-metal total hip arthroplasty. Acta Orthop 2013;84(6): 549–554.
4. Legaye J, Duval-Beaupere G, Hecquet J et al: Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7(2):99–103.
5. Barrey C, Roussouly P, Le Huec JC et al: Compensatory mechanisms contributing to keep the sagittal balance of the spine. Eur Spine J 2013;22(Suppl. 6):S834–S841.
6. Roussouly P, Pinheiro-Franco JL: Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J 2011;20(Suppl. 5):609–618.
7. Lewinnek GE, Lewis JL, Tarr R et al: Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60(2): 217–220.
8. Kennedy JG, Rogers WB, Soffe KE et al: Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty 1998;13(5):530–534.
9. Yamaguchi M, Akisue T, Bauer TW et al: The spatial location of impingement in total hip arthroplasty. J Arthroplasty 2000;15(3):305–313.
10. Zilber S, Lazennec JY, Gorin M et al: Variations of caudal, central, and cranial acetabular anteversion according to the tilt of the pelvis. Surg Radiol Anat 2004;26(6):462–465.
11. Boulay C, Bollini G, Legaye J et al: Pelvic incidence: A predictive factor for three-dimensional acetabular orientation—A preliminary study. Anat Res Int 2014; 2014:594650.
12. Tiberi JV 3rd, Antoci V, Malchau H et al: What is the fate of Total Hip Arthroplasty (THA) acetabular component orientation when evaluated in the standing position? J Arthroplasty 2015;30(9):1555–1560.
13. Langton DJ, Jameson SS, Joyce TJ et al: The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. J Bone Joint Surg Br 2008;90(9):1143–1151.
14. Sidaginamale RP, Joyce TJ, Lord JK et al: Blood metal ion testing is an effectivescreening tool to identify poorly performing metal-on-metal bearing surfaces. Bone Joint Res 2013;2(5):84–95.
15. Bolland BJ, Culliford DJ, Langton DJ et al: High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: Clinical, radiological and retrieval analysis. J Bone Joint Surg Br 2011;93(5):608–615.
16. Matthies AK, Henckel J, Cro S et al: Predicting wear and blood metal ion levels in metal-on-metal hip resurfacing. J Orthop Res 2014;32(1):167–174.
17. Savarino L, Cadossi M, Chiarello E et al:How do metal ion levels change over time in hip resurfacing patients? A cohort study. Sci World J 2014;2014:7.
18. Jantzen C, Jorgensen HL, Duus BR et al: Chromium and cobalt ion concentrations in blood and serum following various types of metal-on-metal hip arthroplasties: A literature overview. Acta Orthop 2013;84(3):229–236.
19. Laaksonen I, Donahue GS, Madanat R et al: Outcomes of the recalled articular surface replacement metal-on-metal hip implant system: A systematic review. J Arthroplasty 2017;32(1):341–346.
20. Qu X, Huang X, Dai K: Metal-on-metal or metal-on-polyethylene for total hip arthroplasty: A meta-analysis of prospective randomized studies. Arch Orthop Trauma Surg 2011;131(11): 1573–1583.
21. Bosker BH, Ettema HB, Boomsma MF et al: High incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement: A prospective cohort study. J Bone Joint Surg Br 2012;94(6):755–761.
22. Reito A, Elo P, Puolakka T et al: Femoral diameter and stem type are independent risk factors for ARMD in the large-headed ASR THR group. BMC Musculoskelet Disord 2015;16:118.

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Original Publications

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Measuring acetabular cup orientation after large-diameter metal-on-metal total hip replacement

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IV

Measuring acetabular cup orientation after large-diameter metal-on-metal total hip replacement

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ABSTRACT

Background and purpose

Assessing position of a metal-on-metal hip implant radiologically might be significantly compromised because of the large diameter metal head obscuring the cup margins. The purpose was to evaluate the reliability of measuring inclination and anteversion angles of a large-diameter metal-on-metal implant by plain radiographs.

Material and Methods

The measurements were performed by two independent observers on a sample of 96 people (100 hips) who had underwent a total large-diameter metal-on-metal hip replacement. Intra- and inter-observer reliability were estimated by using an intraclass correlation coefficient along with Bland-Altman plots.

Results

Both intra- and inter-observer reliability analysis showed nearly perfect agreement with the intraclass correlation coefficient ranging between 0.96 and 0.99. Absolute intra- and inter-observer measurement errors for both inclination and anteversion were approximately one degree.

Interpretation

Assessing acetabular component position by plain radiographs after large-diameter metal-on-metal total hip replacement showed excellent repeatability when performed by the same or two different observers.

Keywords: metal-on-metal, total hip arthroplasty, reliability, plain radiograph, inclination, anteversion

INTRODUCTION

At least one million hips have been replaced with metal-on-metal (MoM) hip implants across the world including hundreds of thousands of large-diameter MoM total hip implants (Lombardi et al. 2012, Registry 2015, Registry 2013). Due to metal wear and adverse reactions to metal debris, MoM implants have demonstrated high complication rates (Langton et al. 2008, Mokka et al. 2013) and because of that, they are closely monitored by orthopaedic surgeons. Even if excluded from today´s surgery arsenal, these implants and their complications are going to burden orthopaedic clinics for years to come (Chang et al. 2013, Lombardi et al. 2015). Predicting MoM problems early is essential for effective and timely correction of complications.
Deviations in MoM acetabular cup orientation have been addressed to be a strong predictor of upcoming MoM adverse effects (De Haan et al. 2008, Langton et al. 2008). Thus, previous research has stressed the importance of assessing acetabular cup orientation as precisely as possible. Additionally to clinical reasons, a reliability of measurement of a large-diameter MoM implant position may, in some cases, be pivotal when clarifying a legal entitlement for compensation (DePuy 2015, Lombardi et al. 2012, Reuters 2014).

The measurements of acetabular components orientation have been well studied on modern metal-on polyethylene, ceramic-on-ceramic, and ceramic-on-polyethylene implants (Lu et al. 2013, Mahmood et al. 2015, Nho et al. 2012, Patel et al. 2011). These measurements have been found reliable in both intra-observer and inter-observer settings. For the purpose, plain radiographs are common and prudent imaging method. The difficulties in measurement have been recognized in situations when implants are entirely metallic – a femoral head, a taper adapter, and a cup. The difficulties grow especially in the case of a total large-diameter MoM implant. It has been suggested that radiological assessment of MoM implant may be significantly compromised because of the large-diameter metal head obscuring the cup margins (Hart et al. 2009, Langton et al. 2010). Few studies only have assessed reliability on MoM resurfacing arthroplasty (Davda et al. 2015, Reito et al. 2012) but none has focused primarily on total MoM implants.

The objective of this study was to assess the intra- and inter-observer reliability of measuring acetabular component inclination and anteversion angles of a large-diameter MoM total hip implant by using plain radiographs.

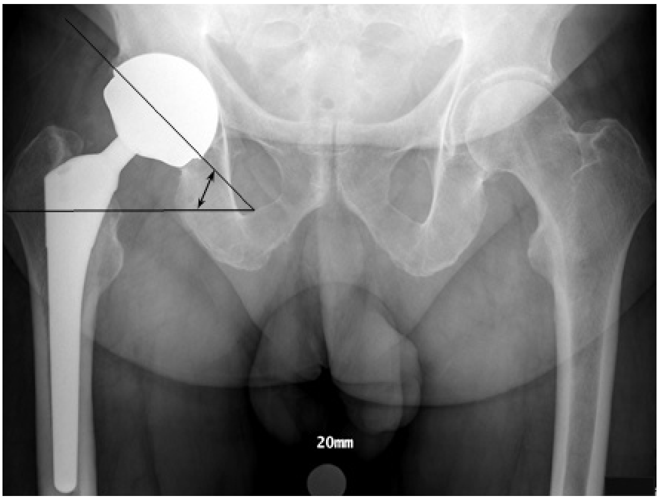

Figure 1A. Measuring the angle of acetabular component inclination

Figure 1B. Measuring the angle of acetabular component anteversion

METHODS

This study was part of an ongoing screening study among patients after large-diameter head MoM total hip arthroplasty in an orthopaedic clinic of university hospital (Mokka et al. 2013). (Mokka et al. 2013). Data on all consecutive patients who underwent a total hip arthroplasty by using a Bi-Metric® ReCap®-M2a-Magnum (Biomet, Warsaw, Ind. USA) implant between 2007 and 2011 were collected. Hip osteoarthritis was the main reason for the surgery. Between April 2014 and February 2015, each patient underwent a standing anteroposterior radiography of the pelvis and a standing lateral radiography of the replaced hip. The hospital ethics committee approved the study.

The radiographs were assessed by two independent researchers – orthopaedic surgeons. For the assessment, they used Carestream PACS® imaging software (Carestream Health, Inc., 2011. Version 11.3 turpacs. Rochester, NY: Onex Corp, USA). Earlier, this kind of digital tools has been reported to be reliable to measuring a total hip implant position (Patel et al. 2011). The observers used a digital Cobb angle tool included in the software. Using pelvis radiographs, they measured the angles of inclination as suggested by Lewinnek et al. (Lewinnek et al. 1978) (Figure 1a). Using lateral hip radiographs, the observers assessed the angles of anteversion as proposed by Murray (Murray 1993) (Figure 1b). All measurements were recorded with accuracy of 1 degree. One of the observers repeated the assessments after one week.

The monoblock press-fit acetabular component of Recap®-M2a-Magnum implant is a hemispherical with shell thickness of 3 millimetres. Mated with an insert taper adapter, a modular head is 6 millimetres smaller than the respective acetabular component. The cup and the head of Recap®-M2a-Magnum articulation are made of a cobalt-chrome-molybdenum alloy. The stem, taper, and taper adapter of this implant are made of a titanium-aluminium-vanadium alloy. In this study, the point of slight change in radiological contour between the edge of the shell and the head was considered the indicator of acetabular component rim (Figure 1a and 1b). The inclination was defined as the direct angle between the line connecting those points and the horizontal line in the anteroposterior pelvic view. The anteversion was defined as the angle between the line connecting those points and the horizontal line in the lateral view.

STATISTICAL ANALYSIS

The distributions of all interval variables were tested for normality. The estimates from normally distributed data were reported as means, standard deviations (SD) and ranges. Otherwise, the results were reported as medians, inter-quartile ranges (IQR), and ranges. The results were accompanied by 95% confidence intervals (95% CIs). The two-way mixed effects model of intra-class correlation coefficient (ICC) was used to quantify the degree to which the observers' assessments resembled each other. The results were reported as single measures ICCs, describing how reliable it is to use only one observer, and as average measures ICCs, describing the reliability of agreement between two observers. ICC was interpreted as follows: 0 to 0.2 – poor agreement, 0.3 to 0.4 – fair agreement, 0.5 to 0.6 – moderate, 0.7 to 0.8 – strong, and >0.8 – almost perfect agreement. Cronbach's alpha was also reported considering alfa ≥ 0.9 excellent, 0.9 to 0.8 – good, 0.8 to 0.7 – acceptable, 0.7 to 0.6 – questionable, 0.6 to 0.5 – poor, and < 0.5 – unacceptable. Bland Altman plots were constructed for each outcome measurement pair plotting the difference between the two measurements per subject against the mean of two measurements (Bland and Altman 1986). The ICC´s were calculated using IBM® SPSS® Statistics version 22 (IBM® Corp. Released 2013. IBM® SPSS® Statistics for Windows 64 bit, Version 22.0. Armonk, NY: IBM® Corp). All the other analyses were performed using Stata/IC Statistical Software: Release 14. College Station (StataCorp LP, TX, USA).

RESULTS

Data on 96 consecutive patients (100 operated hips) were available. Of them four patients had underwent bilateral hip replacement. Of the patients, 53 were men and 43 women. Their age was on average 69.1 (SD 8.6, 48 to 86) years at the day of the imaging. Of the replaced hips, 64 were right and 36 were left. The median time between the arthroplasty and the day of the imaging was 3.4 (IQR 3.1 to 3.65, range 2.5 to 8.2) years. None of the patients needed a revision surgery or had any significant complication of surgery. All the evaluated implants were well osteointegrated. One image was excluded from the anteversion assessment due to its low quality.

INCLINATION

In all three measurements, the inclination angle was on average 43 degrees varying

2A

2B

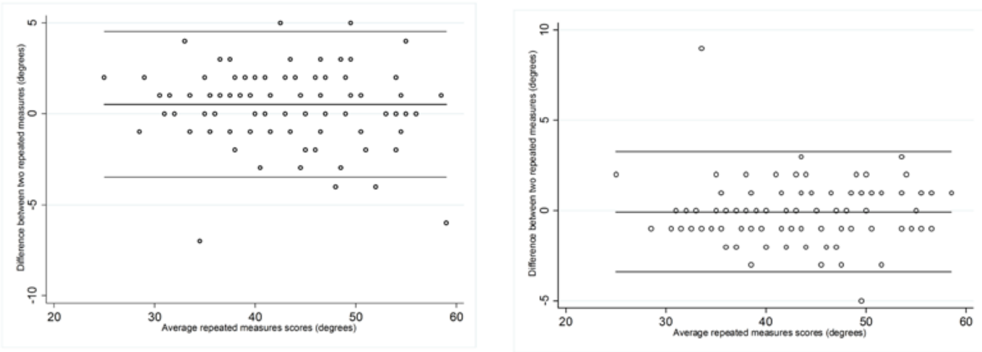

Figure 2. Bland Altman plots of intra- (2A) and inter-observer (2B) reliability of inclination measurements. Dots represent paired measures. The central line denotes the mean difference values. The upper and lower lines denote 95% limits of agreement.

only slightly. The inter-observer measurements comparison showed the median difference of 1 (IQR 0 to 2, range 0 to 9) degree. Assessed by ICC, the inter-observer repeatability was nearly perfect: single measures ICC was 0.97 (95%CI 0.96 to 0.98) and average measures ICC was 0.99 (95%CI 0.98 to 1.0). Cronbach's alfa was 0.99. The intra-observer median difference was 1 (IQR 1 to 2, range 0 to 7) degree. The intra-observer repeatability of assessment was also nearly perfect: single measures ICC was 0.96 (95%CI 0.95 to 0.98) and average measures ICC was 0.98 (95%CI 0.97 to 0.99). Cronbach's alfa was 0.98. The Bland Altman plots confirmed the similarity of repeated measures estimates (Figure 2).

ANTEVERSION

In three measurements, the anteversion angle varied slightly on average from 20 to 21 degrees. The inter-observer measurements comparison showed the median difference of 1 (IQR 0 to 1, range 0 to 10) degree. Assessed by ICC, the inter-observer repeatability was nearly perfect: single measures ICC was 0.99 (95%CI 0.98 to 0.99) and average measures ICC was 0.99 (95%CI 0.99 to 1.0). Cronbach's alfa was 0.99. The intra-observer median difference was 1 (IQR 1 to 1, range 0 to 10) degree. The intra-observer repeatability of assessment was also nearly perfect: single measures ICC was 0.99 (95%CI 0.98 to 0.99) and average measures ICC was 0.99 (95%CI 0.99 to 1.0). Cronbach's alfa was 0.99. In this case, as well, the Bland Altman plots confirmed the similarity of repeated measures estimates (Figure 3).

DISCUSSION

In this cross-sectional study, the plain radiographs of 100 hips replaced with total large-diameter head MoM implants due to osteoarthritis were assessed. The positions of implant acetabular components were measured by inclination and anteversion angles by two independent researcher. Both inter- and intra-observer reliability of assessment was found to be excellent when measured by ICC and Cronbach's alfa. The absolute error of agreement was as small as 1 degree for both inclination and anteversion.

3A 3B

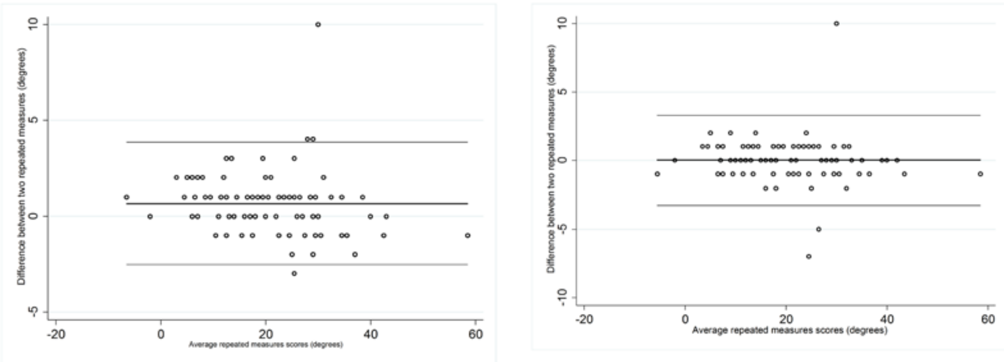

Figure 3. Bland Altman plots of intra- (3A) and inter-observer (3B) reliability of anteversion measurements. Dots represent paired measures. The central line denotes the mean difference values. The upper and lower lines denote 95% limits of agreement.

The sample was big enough to achieve the level of statistical significance. The accuracy of measurements was assured by 0.01-degree preciseness of a digital tool used. However, the sample gathered in one orthopaedic clinic may not represent the variety of entire population of people who underwent the surgery in question, though there were a good variety of angles included in this study sample. None of the patients had any surgery complications and, thus, it is unknown if the reliability persists also in the situations when there are complications or after the revision surgery.

This was the first study evaluating the repeatability of measuring acetabular cup position after a total MoM hip replacement. Thus, there was no previous research comparable with our results directly. Our results support the earlier reports that acetabular component position may be measured reliably from plain radiographs. When evaluating resurfacing implants, Reito et al. (Reito et al. 2012) and Davda et al. (Davda et al. 2015) reported high ICCs for both inclination and anteversion. Previous studies conducted on other than MoM bearings have also reported high reliability of such measurements (Lu et al. 2013, Mahmood et al. 2015).

In this study, reliability figures were higher than the figures reported by the previous research. The reason for that remains unknown hiding possibly in differences in software used. Another reason maybe the fact that the sample was uniform regarding the design of hip implant used. The familiarity of an observer with assessing these particular kinds of radiographs may affect the estimations as well, as occurred in the study of Reito et al (Reito et al. 2012). It may be worth to include these considerations into further research.

Assessing acetabular component position by plain radiographs after large-diameter metal-on-metal total hip replacement showed excellent repeatability when performed by the same or by two different observers. Our results support the use of plain radiographs as a routine imaging technique when screening for complications associated with MoM total hip implants. ●

REFERENCES

Bland J M, Altman D G. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1 (8476): 307-10.

Chang E Y, McAnally J L, Van Horne J R, Van Horne J G, Wolfson T, Gamst A, et al. Relationship of plasma metal ions and clinical and imaging findings in patients with ASR XL metal-on-metal total hip replacements. J Bone Joint Surg Am 2013; 95 (22): 2015-20.

Davda K, Smyth N, Cobb J P, Hart A J. 2D measurements of cup orientation are less reliable than 3D measurements. Acta Orthop 2015; 86 (4): 485-90.

De Haan R, Campbell P A, Su E P, De Smet K A. Revision of metal-on-metal resurfacing arthroplasty of the hip: the influence of malpositioning of the components. J Bone Joint Surg Br 2008; 90 (9): 1158-63.

DePuy. 2015. Available from http://www.asrhipinfo.com.au.

Hart A J, Dandachli W, Schlueter-Brust K, Henckel J, Cobb J. Large ball metal on metal hips obscure cup angle measurement on plain radiographs. Hip Int 2009; 19 (4): 323-9.

Langton D J, Jameson S S, Joyce T J, Webb J, Nargol A V. The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. J Bone Joint Surg Br 2008; 90 (9): 1143-51.

Langton D J, Sprowson A P, Mahadeva D, Bhatnagar S, Holland J P, Nargol A V. Cup anteversion in hip resurfacing: validation of EBRA and the presentation of a simple clinical grading system. J Arthroplasty 2010; 25 (4): 607-13.

Lewinnek G E, Lewis J L, Tarr R, Compere C L, Zimmerman J R. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978; 60 (2): 217-20.

Lombardi A V, Jr., Barrack R L, Berend K R, Cuckler J M, Jacobs J J, Mont M A, et al. The Hip Society: algorithmic approach to diagnosis and management of metal-on-metal arthroplasty. J Bone Joint Surg Br 2012; 94 (11 Suppl A): 14-8.

Lombardi A V, Jr., Berend K R, Morris M J, Adams J B, Sneller M A. Large-diameter metal-on-metal total hip arthroplasty: dislocation infrequent but survivorship poor. Clin Orthop Relat Res 2015; 473 (2): 509-20.

Lu M, Zhou Y X, Du H, Zhang J, Liu J. Reliability and validity of measuring acetabular component orientation by plain anteroposterior radiographs. Clin Orthop Relat Res 2013; 471 (9): 2987-94.

Mahmood S S, Al-Amiry B, Mukka S S, Baea S, Sayed-Noor A S. Validity, reliability and reproducibility of plain radiographic measurements after total hip arthroplasty. Skeletal Radiol 2015; 44 (3): 345-51.

Mokka J, Junnila M, Seppanen M, Virolainen P, Polonen T, Vahlberg T, et al. Adverse reaction to metal debris after ReCap-M2A-Magnum large-diameter-head metal-on-metal total hip arthroplasty. Acta Orthop 2013; 84 (6): 549-54.

Murray D W. The definition and measurement of acetabular orientation. J Bone Joint Surg Br 1993; 75 (2): 228-32.

Nho J H, Lee Y K, Kim H J, Ha Y C, Suh Y S, Koo K H. Reliability and validity of measuring version of the acetabular component. J Bone Joint Surg Br 2012; 94 (1): 32-6.

Patel S R, Toms A P, Rehman J M, Wimhurst J. A reliability study of measurement tools available on standard picture archiving and communication system workstations for the evaluation of hip radiographs following arthroplasty. J Bone Joint Surg Am 2011; 93 (18): 1712-9.

Registry A O A N J R. 2015. Available from https://aoanjrr.dmac.adelaide.edu.au.

Registry N J. 2013. Available from http://www.njrcentre.org.uk.

Reito A, Puolakka T, Paakkala A, Pajamaki J. Assessment of inter- and intra-observer reliability in the determination of radiographic version and inclination of the cup in metal-on-metal hip resurfacing. Int Orthop 2012; 36 (3): 519-25.

Reuters. 2014. Available from http://reuters.com/article/2014/02/04/us-biomet-settlement-idUSBREA1305Y20140204