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The Soft Tissues in Osteoarthritis and Arthroplasty of the Hip

Tarasevicius, Sarunas

2009

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Citation for published version (APA):

Tarasevicius, S. (2009). *The Soft Tissues in Osteoarthritis and Arthroplasty of the Hip*. [Doctoral Thesis (compilation), Orthopaedics (Lund)]. Department of Clinical Sciences, Lund University.

Total number of authors:

1

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

THE SOFT TISSUES IN OSTEOARTHRITIS AND ARTHROPLASTY OF THE HIP

Sarunas Tarasevicius



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ISSN 1652-8220

ISBN 978-91-86253-41-7

Lund University, Faculty of Medicine Doctoral Dissertation Series 2009:53

Sarunas Tarasevicius: THE SOFT TISSUES IN OSTEOARTHRITIS AND ARTHROPLASTY OF THE HIP – Thesis, Lund 2009

Thesis
Lund University
2009



Department of Orthopedics, Clinical Sciences, Lund University,
Lund, Sweden

The soft tissues in osteoarthritis and arthroplasty of the hip

Sarunas Tarasevicius



Thesis 2009

Contact address

Sarunas Tarasevicius
Department of Orthopedics
University Hospital
SE-221 85 Lund
Sweden
email: Sarunas.Tarasevicius@med.lu.se

Layout by Ortonova AB

Cover photo: Uldis Kesteris, ©Keforto AB, tel: +46 704 604 525

ISSN 1652-8220

ISBN 978-91-86253-41-7

Lund University, Faculty of Medicine Doctoral Dissertation Series 2009:53

Printed in Sweden

Mediatryck, Lund

2009

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Abbreviations

- BMI** – Body Mass Index
CRR – Cumulative revision rate
CT – Computerised tomography
HOOS – Hip disability and osteoarthritis outcome score
ICC – Intraclass correlation coefficient
ICP – Intracapsular hydrostatic pressure
MRI – Magnetic resonance imaging
OA – Osteoarthritis
PE – Polyethylene
RSA – Roentgen stereophotogrammetry
THA – Total hip arthroplasty
UCLA – University of California Los Angeles activity score
UHMWPE – Ultra high molecular weight polyethylene
US – Ultrasound/sonography
VAS – Visual analogue scale

List of Papers

This thesis is based on the following papers, in the text referred to by their Roman numerals:

- I** Tarasevicius S, Skikas L, Mitraite D, Torii Y, Kesteris U, Wingstrand H. Sonography in total hip arthroplasty. *Ultraschall Med* 2007; 28(5): 475-8.
- II** Tarasevicius S, Kesteris U, Gelmanas A, Smailys A, Wingstrand H. Intracapsular pressure and elasticity of the hip joint capsule in osteoarthritis. *J Arthroplasty* 2007; 22(4): 596-600.
- III** Tarasevicius S, Kesteris U, Kalesinskas RJ, Wingstrand H. Dynamics of hip joint effusion after posterior soft tissue repair in total hip arthroplasty. *Int Orthop* 2006; 30(4): 233-6.
- IV** Tarasevicius S, Robertsson S, Kesteris U, Kalesinskas RJ, Wingstrand H. Effect of femoral head size on polyethylene wear and synovitis after total hip arthroplasty. A sonographic and radiographic study of 39 patients. *Acta Orthop* 2008; 79(4): 489-93.
- V** Tarasevicius S, Gelmanas A, Smailys A, Robertsson O, Wingstrand H. Short rotator tendons do not increase intracapsular pressure in severe osteoarthritic hips *BMC Musculoskeletal Disorders* 2009; 10: 12.

Introduction

Osteoarthritis is usually characterized by degenerative changes in the articular cartilage and bone of affected joints (Lloyd-Roberts 1953). The degenerative process of the cartilage layer is gradually accompanied by degenerative changes of the joint capsule, menisci, ligaments and bone. These changes can be identified on plain radiographs and/or with other imaging methods. Radiography is the recommended imaging modality for the assessment of disease severity. Joint space narrowing, osteophyte formation, and subchondral sclerosis can be identified on plain radiographs. In early stages of OA these methods are flawed. Joint space narrowing will not appear until the advanced erosive stage (Pollard et al. 2008). More sensitive methods are necessary to monitor early disease. CT arthrography is sensitive in detecting early structural cartilage lesions (Alvarez et al. 2005) and may be superior to plain MRI (Nishii et al. 2005). However, MRI has the advantage over CT in that it can image all tissues within the joint, and specific sequences focusing on cartilage (Eckstein et al. 2006) give a detailed and quantitative image of cartilage morphology. In a clinical trial, progression of disease may be defined according to endpoints that indicate how a patient feels, functions or survives.

A surrogate outcome measure may substitute for a clinically relevant endpoint, wherein lies a role for biomarkers (Pollard et al. 2008). Biomarkers are biochemical substances whose potential applications are in the understanding of disease processes, identification of molecular targets, assessment of disease severity, and risk of progression (Lohmander and Eyre 2005). The OA biomarkers are measured in serum or urine levels, but there are problems; their validation is difficult and may be confounded by age, gender, ethnicity, body mass index and comorbidity. Many biomarkers have been investigated (Garnero et al. 2000, Garnero and Delmas 2003). Degradation of type II collagen may be measured in urine by testing for fragments of the helical (Helix-II) or C-telopeptide regions (CTX-II), localized primarily in hyaline cartilage.

Helix II levels are elevated in destructive OA of the hip (Garnero et al. 2006), and CTX-II is elevated in OA patients and predicts the severity and progress of OA of the knee (Garnero et al. 2001, Garnero et al. 2002). Whether these are the optimum markers for early OA is unclear.

Cartilage oligomeric matrix protein has been extensively studied as a possible biomarker. Elevated serum levels of this biomarker occur in OA of the knee (Garnero et al. 2001) and are associated with reduced cartilage volume (Sharif et al. 2004). However cartilage oligomeric matrix protein is not exclusive to cartilage and is also present in other connective tissues e.g. synovium and meniscus, thus this biomarker reflects synovitis, indicating a lack of specificity which necessitates cautious interpretation of its role as a OA biomarker (Vilim et al. 2001).

The majority of research projects in this field were focused on the analysis of changes in cartilage and bone, but the soft tissues surrounding the OA hip joint were rarely investigated. However, it has been shown that changes in soft tissues play a role in OA and THA hips. Pathology in soft tissues, e.g. the joint capsule and synovium, may contribute to pain and decreased range of motion due to increased hydrostatic pressure (Goddard and Gosling 1988, Robertsson et al. 1995). The role of hip joint capsule elasticity and short rotators in the OA hip and its relation to hip joint function, disease progress and pain are not fully understood.

After the OA joint has been replaced with THA the soft tissues, including postoperative scar tissue, continue to play a role in joint biomechanics and biology. In the loosening of the prosthetic components, which is the most frequent cause of failure in THA, the soft tissues surrounding the prosthetic hip may play a substantial role. Schmalzried et al. (1992) introduced the term "effective joint space", describing joint fluid distribution, migration, and transportation of PE wear debris in the THA joint. The authors stated that PE wear debris and other particles are dispersed in the joint fluid. They also

claimed that the joint fluid migration around the implant is strongly depending on contact durability between prosthesis and bone. The variability of implant-bone contact durability determines the access routes for the joint fluid and particulate debris to the prosthesis/cement-bone interface. Joint fluid flows according to pressure gradients and simply follows the path of least resistance. The areas where joint fluid reaches bone become a part of the joint space and different mechanisms (mechanical pressure, inflammatory response) induce osteolysis in these exposed areas of the bone. If this is true then the periprosthetic soft tissues play a role in the pumping mechanism of fluid due to abnormal elastic properties and compliance.

However the interaction of fluid, hydrostatic pressure, particles and prosthetic hip joint capsule in the loosening process is poorly understood.

Hip joint osteoarthritis and pain

There are several theories explaining the pain in the OA hip. According to Felson (2005) pain arises from articular cartilage lesions due to mechanical irritation of loose cartilage flaps. Fernandes et al. (2002) stated that pain arises from synovial and capsular inflammation and/or from subchondral bone sclerosis that acts on the periarticular nerve endings. Synovial/capsular inflammation causes the release of inflammatory cytokines, in particular interleukin-1 and tumor necrosis factor, factors known to induce production of proteolytic enzymes by articular chondrocytes (Goldring 1999). Goddard and Gosling (1988) described the term „capsular pain” in the OA hip and suggested that capsular pain results from stimulation of stretch receptors in the joint capsule, and that the subsequent spasm is a protective reflex. Lemperg and Arnoldi (1978) studied the relation between pain and intraosseous venous pressure in OA hips and found that increased pain correlated to high resting intraosseous venous pressure. The authors suggested that high intraosseous venous pressure resulted from disturbed circulation in periarticular veins, secondary to high pressure within the hip capsule.

Intracapsular pressure and pain in osteoarthritis

It is empirically accepted that an effusion in a joint is painful, and that aspiration of the fluid is usually followed by the relief of pain. There are several hip joint disorders where increased intracapsular hydrostatic pressure is related to pain; e.g. transient synovitis (Wingstrand et al. 1985), septic arthritis (Wingstrand et al. 1987) and juvenile chronic arthritis (Rydholm et al. 1986). Robertsson et al. (1995) investigated OA patients and found a correlation between ICP and pain. Goddard and Gosling (1988) reported high resting ICP in younger patients with more mobile and more painful hips, and lower ICP in older patients with stiffer and less painful hip joints. These authors claimed that increased ICP was primarily responsible for the pain in these OA patients, and that pain was transmitted through nerves indentified in the synovial membrane.

Properties of the hip joint capsule

Wingstrand et al. (1990) and Wingstrand and Wingstrand (1997) found that in the normal hip there is no change in intracapsular volume, ICP, stretching, or tension in the capsule within the normal range of hip joint motion. In healthy hips the capsule is tightened only in positions of extreme rotation around the axis of the femoral neck. The prerequisite for this “pressureless” range of motion is the hyperboloid shape of the joint capsule. If this hyperboloid shape is distorted towards a more cylindrical shape, due to any kind of pathological changes such as synovial edema and/or intraarticular effusion, rotation of the hip causes a decreased range of pressureless motion, and subsequently pain.

Furthermore, mechanical joint stability is primarily, not taking into account the muscular tone, maintained by the effect of the atmospheric pressure (Wingstrand and Wingstrand 1997).

Ultrasound in the prosthetic hip

Although widely used in different medical areas US is to date not a routine method of examination

in THA. US in THA was described by Földes et al. (1992). The authors investigated the potential of US in the detection of THA hip joint effusion. They analyzed the usefulness of US in THA, and concluded that US has a potential to identify effusions in THA hips, and that it is a helpful tool in guiding the cannula in joint fluid aspiration. A few years later Van Holsbeeck MT et al. (1994) investigated the usefulness of US in the detection of joint effusion in infected loose hip prostheses. They concluded that with US it is possible to detect not only increased THA joint fluid, but also to detect communicating and non-communicating cavities and abscesses. Furthermore, Kesteris et al. (1999) have demonstrated a significant correlation between radiographic signs of wear and loosening of the polyethylene cups and sonographically measured anterior capsular distension in cemented THA.

Ultrasound of the hip in children is very well described and validated (Egund et al. 1986, Laurell et al. 2002), but we could not find any reports in the literature on the reliability of US in THA.

Prosthetic dislocation and soft tissues

Dislocations of hip prosthesis, in particular recurrent dislocations, remain a serious complication. Interestingly, the dislocation rate in THA has remained more or less on the same level over time regardless of increased general knowledge and 50 years experience with the procedure. Different surgical approaches have been developed, some of which have reduced the dislocation rate. The major benefit with posterior surgical approach is its excellent exposure of both acetabulum and femur. However, many series have reported that the dislocation rate is 2 to 3 times greater after primary THA in which the posterior approach was used as compared to THA with anterior approach (Morrey 1992). There are, however, additional factors affecting the dislocation rate after THA. These include the orientation of the components, femoral head size, and patients' compliance (He et al. 2007, Conroy et al. 2008).

In order to reduce the dislocation rate after posterior approach Pellicci et al. (1998) developed the posterior soft tissue repair technique. The aim of posterior repair was to reconstruct, as completely

as possible, the posterior soft tissue sleeve. The posterior repair included reattaching piriformis and conjoint tendons to the greater trochanter through drill holes. Previously, Johnsson et al. (1981) had described a modified technique to reinsert the short rotators together with bone shell after posterior approach. Early results have suggested a decreased dislocation rate with posterior repair (White et al. 2001), and it seems logical that reattaching all the structures that are detached during posterior exposure and restore normal anatomy would prevent posterior dislocation. However, an increased volume of intracapsular fluid must be taken into consideration since it might facilitate dislocation following THA. Free fluid, e.g. postoperative hematoma/seroma or later synovitis with free fluid, is likely to facilitate dislocations in the THA hip since the stabilizing effect of the atmospheric pressure is eliminated if there is a significant volume of free fluid in the joint (Wingstrand and Wingstrand 1997). This is in concordance with the findings of Zwartelee et al. (2004), suggesting that inflammatory arthritis might be considered as an independent risk factor for dislocation after primary THA. The usual intraoperative finding in THA rheuma patients when the hip joint capsule is incised, a great amount of fluid, suggests that inflammatory arthritis is associated with increased production of joint fluid. Posterior soft tissue repair should theoretically reduce the fluid filled "dead space" as named by Pellicci et al. (1998) and this might be one factor, besides the mechanical support, which decreases the dislocation rate after THA. However, the effect of posterior repair on the intraarticular fluid/synovial edema is not yet studied.

Prosthetic loosening and polyethylene wear

Aseptic loosening of the prosthetic components in the THA is the main cause of revision surgery. The mechanisms inducing loosening are not completely understood. Polyethylene wear induced osteolysis has been a generally accepted hypothesis (Willert 1977). Long term studies have demonstrated a relation between the amount of PE wear and loosening (Wroblewski and Siney 1993, Hamilton and

Gorczyca 1995). Wear debris was found in loose hips (Howie 1990, Athanasou et al. 1992), but a few authors reported that polyethylene particles were not always present in the areas where osteolysis occurred (Maloney et al. 1990, Willert et al. 1990). It has also been demonstrated that polyethylene debris can activate macrophages and cause a foreign body reaction (Murray and Rushton 1990, Willert et al. 1990), and that this could be a cause of bone resorption (Athanasou et al. 1992). Howie et al. (1988) presented an animal study in which PE particles alone were found to cause bone resorption in the absence of motion or infection, but later studies did not confirm these results (Howie et al. 1993, Van Der Vis et al. 1997). Thus, PE particles may not be the only cause of osteolysis. Other factors explaining the development of prosthetic loosening were suggested. Initial migration of the prosthetic components has been described by several authors as a crucial factor in late aseptic loosening (Mjoberg 1994, Aspenberg and van der Vis 1998). This hypothesis was based on RSA-results and scintigraphic findings indicating early migration of prosthetic components (Mjoberg 1994). It was shown that early migration is a good predictor

of late aseptic loosening (Krismer et al. 1996, Kärrholm et al. 1997).

The mechanism of PE particle migration was suggested by Schmalzried et al. (1992). They presented the term “effective joint space”, describing joint fluid distribution, migration, and transportation of PE wear debris in THA hips, and their finding were in concordance with another theory explaining aseptic loosening, suggesting that osteolysis might occur due to increased mechanical load and disturbed blood circulation in the bone because of increased static and dynamic fluid pressure (Robertsson et al. 1997, Aspenberg 1998, Walter et al. 2004). A correlation between loosening and capsular distension due to increased ICP, i.e. the sonographically measured distance between the prosthetic femoral neck and the anterior capsule of the hip joint, was demonstrated (Robertsson et al. 1997, Kesteris et al. 1999). Robertsson et al. (1997) also found a correlation between sonographically measured capsular distension and ICP.

It is still unknown what triggers an increase in ICP in loose THA hips. Also it is a question how increased ICP affects PE wear, or possibly how PE wear affects the ICP.

Author's studies

US as a method of examination has so far rarely been used investigating THA hips for signs of infection or synovial edema/free fluid in the joint. We could not find any papers in the literature describing the reliability of US measurements of anterior capsular distance in prosthetic hips. Consequently, the intra- and interobserver agreement with this particular investigation was not before evaluated. In Paper I we investigated the accuracy of US in measuring the anterior capsular distance in THA hips; and the effect of experience in this method of examination.

There were reports in the literature that hip joint effusion might be responsible for pain in OA hips (Goddard and Gosling 1988, Robertsson et al. 1995). These authors suggested that pain might be of capsular/synovial origin due to its rich sensory innervation (Kellgren and Samuel 1950). Little has been written about the mechanical properties of the capsule and how they may differ in various stages of OA disease. In Paper II we investigated the intracapsular pressure and the elasticity of the hip joint capsule in OA and correlated these parameters to pain and to the radiographic stage of OA in these hips.

Joint dislocation remains one of the most disturbing complications after THA. The posterior surgical approach is most commonly used in THA, but also has higher dislocations rates (Morrey 1992) as compared to lateral or anterior approaches. The reconstruction of posterior soft tissues after THA with posterior approach was developed to cope

with this complication and was reported to reduce the dislocation rate (Pellicci et al. 1998). The aim of this surgical technique was to restore, as much as possible, the normal anatomy, thus eliminating the postoperative "dead space" in the hip. In Paper III we investigated the sonographically measured capsular distance, indicating the level of intracapsular pressure in THA hips with or without posterior soft tissue repair.

Aseptic loosening of the prosthetic components limits the longevity of the THA and is the main cause of revision surgery. Osteolysis induced by polyethylene wear has for a long period of time been an accepted explanation for such loosening (Willert et al. 1977, Schmalzried et al. 1992). Other theories explaining the development of loosening, increased hydrostatic intracapsular pressure or initial instability, have however been presented. Robertsson et al. (1997) and Kesteris et al. (1999) found a correlation between sonographically measured capsular distance and loosening. A study was performed and published in Paper IV to investigate the correlation between the sonographically measured capsular distance and PE wear in radiographically stable THA hips.

In Paper II we could not find any correlation between pain and intracapsular pressure which was the case in previous studies by Goddard and Gosling (1988) and Robertsson et al. (1995). A role of the short rotators was suggested as a possible reason. In Paper V we investigated the role of the short rotators on intracapsular pressure in OA hips.

Aims of the studies

The aims of this study were:

- to evaluate the potential of ultrasound in measuring the capsular distance in THA hips (Paper I).
- to investigate the intracapsular pressure and elasticity of the joint capsule, i.e. capsular compliance, and its relation to radiographic stages of hip OA, and in relation to pain, symptoms, and function (Paper II).
- to evaluate the effect of the posterior soft tissue repair in THA on the volume of intraarticular fluid/synovial edema, as indicated by the capsular distension, in the prosthetic hip during the first postoperative year (Paper III).
- to evaluate the linear/volumetric PE wear, for 2 prosthetic head sizes, and age, sex, activity level, or capsular distension, i.e. increased synovia and/or increased synovial edema in THA hips with no or minor clinical or radiographic signs of loosening 10–11 years after surgery (Paper IV) .
- to investigate if perioperative release of the short rotator tendons in osteoarthritic hips affects ICP, and if there is a correlation between ICP and pain before and after release of the short rotators (Paper V).

Summary of Papers

Study I: Sonography in total hip arthroplasty

Objective: The distance between the the anterior surface of the neck of the prosthetic stem and the anterior joint capsule, the capsular distance, is increased in total hip arthroplasty (THA) with synovitis. With this study we evaluated the potential of US in measuring the capsular distance in THA hips one year after insertion.

Materials and methods: We compared the measurements of the capsular distance using a caliper/ruler with those performed with US. A plastic pelvis and femur model with a prosthetic hip and paper tape to simulate the joint capsule was used. We also evaluated the intra- and interobserver agreements between 3 examiners of the US measurements of the anterior capsular distance in 22 patients with THA.

Results: There was a high correlation when measuring the anterior capsular distance in the prosthetic hip model with a ruler as compared with US, ($p < 0.001$). The interobserver agreement in the US measurements was 0.19 CI (0–0.61) for the first 11 patients and became 0.67 CI (0.35–0.89) for the following 11 patients, after examiners gained experience in this procedure. The intraobserver agreement was always better than the interobserver agreement and also improved with increasing number of examinations.

Conclusion: Ultrasonography is a reliable method to measure the anterior capsular distance in THA, especially if performed by an experienced examiner.

Study II: Intracapsular pressure and elasticity of the hip joint capsule in osteoarthritis

Objective: The causes of pain in the OA hip are unclear. Changes in hydrostatic ICP have been suggested as one of the pain causing factors. The biomechanical properties of the hip joint capsule,

such as elasticity, i.e. the compliance of the capsule, and its correlation to symptoms, severity of OA, joint effusion and hydrostatic ICP have to our knowledge not previously been investigated. It is still unknown how prolonged synovitis/joint effusion, capsular tension and the severity of the OA affect the elasticity of the capsule. The purpose of this study was consequently to investigate the intracapsular pressure and elasticity of the joint capsule, i.e. capsular compliance, and its relation to radiographical stages of hip OA, and in relation to pain, symptoms, and function.

Materials and methods: We analyzed 31 unselected patients with hip osteoarthritis admitted for total hip replacement. The evaluation was based on estimation of radiographic osteoarthritis grade, HOOS hip score, sonographic measurements of capsular distance i.e. the distance between the anterior capsule and femoral neck. Intracapsular pressure was measured peroperatively with a Touhy needle connected to a closed, non-volume consuming, sterile, monitoring set for invasive pressure connected to a pressure transducer, and inserted in the hip joint before excision of the capsule. The hydrostatic intracapsular pressure with the hip in 45° of flexion was recorded, as well as in extension, extension-inward, and extension-outward rotation. Following these static pressure registrations we injected an increasing volume of saline, 1ml at a time, into the joint with 3 sec intervals between injections. The intracapsular pressure was continuously recorded until the intracapsular pressure reached 300mmHg which was the upper limit set to the pressure transducer. This recorded pressure/volume curve reflects the elasticity/compliance of the capsule, which could then be calculated in each individual hip.

Results: The mean sonographic capsular distance was 9.9 mm (SD 3.6). The mean intracapsular pressure in 45° of hip flexion was 2.2 mmHg (SD 10.0), compared with in extension 15.8 mmHg (SD 33.0) ($p = 0.007$), in inward rotation 13.7 mmHg (SD 26.0) ($p = 0.001$), and in outward rotation 12.1 mmHg (SD 24.3) ($p = 0.004$).

The mean volume of saline injected into the joint to achieve 300 mmHg intracapsular pressure was 3.6 ml (SD 3.3). The elasticity/compliance of the joint capsules varied between 28 mmHg/ml – 300 mmHg/ml. There were significant correlations between the severity of OA and intracapsular pressure ($p=0.01$) as well as between the severity of OA and compliance of the hip joint capsule ($p=0.02$).

Conclusion: We conclude that an increased radiographic severity of OA is correlated to decreased elasticity/compliance of the joint capsule and with decreased intracapsular hydrostatic pressure.

Study III: Dynamics of hip joint effusion after posterior soft tissue repair in total hip arthroplasty

Objective: Dislocation after total hip replacement is more common in the early, postoperative period. Postoperative intraarticular hematoma and remaining seroma fluid and/or weakened posterior soft tissue wall may be contributing factors. The purpose of this study was to determine how the posterior soft tissue repair in THA affects the volume of intraarticular fluid/synovial edema (capsular distension) in the prosthetic hip at six and 12 months after the operation.

Materials and methods: We investigated 33 consecutive, unselected patients with hip osteoarthritis admitted for THA. All of them were operated on with the same type of cemented implant. Patients were randomized for posterior soft tissue repair or not. Sonography, measuring the anterior capsular distension, indicating the volume of intraarticular fluid/synovial edema in the prosthetic hip joints, was performed after 6 and 12 months in all patients.

Results: We found that at 6 months postoperatively an increased capsular distension, indicating a remaining volume of intraarticular fluid/synovial edema, was greater in the group with posterior soft tissue repair as compared to the group without. After one year the capsular distension decreased in both groups and there was no significant difference between the groups.

Conclusion: We conclude that posterior soft tissue repair in THA is associated with increased capsular distension during the first six months, indicating an increased postoperative intraarticular

dead space. After 12 months there was no difference with or without posterior soft tissue repair.

Study IV: Effect of femoral head size on polyethylene wear and synovitis after total hip arthroplasty. A sonographic and radiographic study of 39 patients

Objective: The role of synovitis and increased intracapsular hydrostatic pressure in the loosening process after THA has gained increased attention. This study aimed to investigate if polyethylene wear, for two different head sizes, was correlated to age, gender, activity level and capsular distension, i.e. increased synovial edema/synovia.

Materials and methods: We analyzed 39 unrevised, radiographically stable hips that had been operated because of osteoarthritis 10 years earlier with 28 or 32 mm femoral heads. We evaluated radiographic signs of loosening, linear and volumetric polyethylene wear, body mass index, activity level and age. Sonographic examination was performed to measure the capsular distance, i.e. the distance between the prosthetic femoral neck and the anterior capsule.

Results: Linear wear was 0.09 (SD 0.05) mm/year and 0.18 (SD 0.09) mm/year in the 28 mm and 32 mm group, respectively ($p<0.001$). The volumetric wear was 51 (SD 28) mm³/year and 136 (SD 70) mm³/year ($p<0.001$) and the capsular distance was 13 mm (SD 3) and 17 mm (SD 3), respectively ($p<0.001$). There was a correlation between linear ($r=0.54$), volumetric ($r=0.62$) wear and capsular distance ($p<0.001$). Cup inclination angle, PE wear direction angle, patients age, activity level, BMI had no significant correlation with PE wear and capsular distension.

Conclusion: Wear was greater for the larger femoral head and was correlated to capsular distension.

Study V: Short rotator tendons do not increase intracapsular pressure in severe osteoarthritic hips

Objective: It is generally accepted that synovial edema/synovia in the hip joint is painful. While a

relation between pain and intracapsular pressure in the hip joint has previously been reported, a newly published study including patients with severe osteoarthritis was not able to confirm this finding. However, the pressure measurements in this study had been performed after cutting the short internal rotators of the hip suggesting that release of short rotators might decompress the hip joint capsule and subsequently result in a lower intracapsular pressure. Our aim was to investigate the role of short rotators in relation to intracapsular pressure and pain in osteoarthritic hips.

Materials and methods: We measured the intracapsular hydrostatic pressure preoperatively in 25 total hip arthroplasty patients with severe osteoar-

thritis in various positions of the hip joint before and after short rotator release, and correlated these pressures to preoperative pain.

Results: Release of the short rotators did not change the intracapsular pressure in any position except in 45° flexion, in which the pressure increased ($p=0.002$). We found no correlation between intracapsular pressure and pain before or after short rotator release.

Conclusion: We conclude that the tension in the short rotator tendons does not increase the intracapsular pressure in radiographically severe OA hips, and that there is no correlation between pain and intracapsular pressure in late OA stages.

Discussion

Reliability of sonography in THA

Sonography is not up to date used as a routine method in diagnostics in THA hips, and thus there has been no data on its reliability and possible usefulness. In the first part of the study I we evaluated the accuracy of US in measuring the anterior capsular distance, i.e. the distance from the anterior surface of the neck of the stem to the anterior surface of the capsule. There was a high correlation between distances measured with a calliper/ruler and US ($r=0.998$). Laurell et al. (2002) demonstrated a high correlation between US measurements of the capsular distance and those from MRI scans, and they showed a good intra- and interobserver agreement in US measurements of the anterior capsular distance of the hip in children. The results of our study I also demonstrated that it is of importance to perform the US examination of the THA hip correctly. Thus, in the ideal situation, the capsular distance in the THA hip should be measured when the echoes from the head and neck of the stem and the rest of the osseous neck are as distinct as possible, and are visible on one and the same US image. This situation ensures that the transducer is correctly placed in the plane of the central axis of the neck of the prosthetic stem. At each following examination this position of the transducer should be reproduced by identifying those three important echoes in the image. This in turn will assure that the capsular distance is repeatedly measured as correctly as possible in the same plane. Thus, the crucial issue of repeated measurement technique is to identify the same plane through the THA hip, and the same point on the anterior joint capsule to measure from. Initially this was not always easy, however, and in some cases it was not possible. The difficulties arise mainly because of disturbing echoes from the structures close to hip joint, and sometimes a very diffuse echo from the joint capsule. With increasing experience, however, those difficulties were partially overcome. Consequently, significantly improved interobserver and intraobserver agreements were achieved with increasing

number of measurements in study I part 2. We were not able to identify a significant increase in intraobserver agreement with increasing number of examinations for the experienced examiner who had previous experience in sonography of THA. For the other two examiners, with no previous experience, ICC increased with increasing experience. An even greater increase in ICC was noticed in interobserver agreement (from 0.19 up to 0.67), indicating that identifying and reproducing the relevant echoes and their relations in the image plays an important role.

Lower interobserver agreement as compared to intraobserver agreement in the second part of study I may be explained by the not always correct positioning of the transducer. It could be seen from images taken during measurements that the same structures were identified, but the transducer was in some cases not accurately orientated in the plane of the central axis of the neck of the prosthetic stem. Egund et al. (1986) have described this and other pitfalls in sonography of the hip.

Pain, intracapsular pressure and elasticity of the joint capsule in OA

In studies II and V we investigated the mechanical properties of hip joint capsule and its relation to surrounding tissues in OA hips. In the normal hip joint there is no increase in intracapsular pressure within the normal range of motion. The presence of synovitis and/or intracapsular fluid decreases this pressureless range of motion and causes tension in the synovium/joint capsule and increased intracapsular pressure (Wingstrand et al. 1990). The differences in intracapsular pressure that we found in studies II and V in various hip positions confirm the presence of synovitis and/or intracapsular fluid in these OA hips. In study II less severe OA was associated with higher intracapsular pressure, i.e. more synovitis/synovial edema and/or intracapsular fluid in the hip. This increase in intracapsular pressure in early OA stages may result in compro-

mised drainage of joint fluid through subsynovial veins as suggested by Arnoldi and Linderholm (1972). As OA progresses, the capsular elasticity decreases with increased capsular contracture, a decrease in the pressureless range of joint motion, and the amount of intraarticular fluid decreases. Such a "dry" joint is the usual preoperative finding in the late stage of OA. This is in accordance with our findings in study II of a negative correlation between the severity of OA and elasticity of the joint capsule.

We found no correlation between pain and capsular distension as measured sonographically in study II. Bierma-Zeinstra et al. (2000) reported a correlation between joint effusion and pain in comparison with healthy hips, whereas in patients with severe OA it is probably more difficult to find a correlation between pain and capsular distension. These patients, like rheumatoid arthritis patients, adapt to these conditions (Rydholm et al. 1986).

Contrary to Goddard and Gosling (1988) and Robertsson et al. (1995) we were not able to find any correlation between pain and intracapsular pressure. Several reasons possibly influenced the differences in our results. One is the difference in pain evaluation methodology. Robertsson et al. (1995) and Goddard and Gosling (1988) evaluated the severity of pain with VAS, zero representing no pain and 10 the worst imaginable pain. We initially also used VAS for pain evaluation, but since our elderly patients had difficulties in understanding VAS we changed to the HOOS (Nilsson et al. 2003) hip score evaluation. In our experience it was easier for the elderly to understand, and represents more adequately pain, function and symptoms of the hip.

A second reason that may explain the lack of pain/pressure correlation in studies II and V was the possible difference in severity of OA in our patients as compared with those in the Robertsson et al. (1995) series. The mean OA grade in our series was 8 (out of 11), i.e. majority of patients in our series had severe OA. In the paper by Robertsson et al. (1995) the OA grade was not evaluated, but according to personal communication with the authors, not as severe as in our studies II and V. That lower intracapsular pressure is associated with more severe OA might influence the lack of pain/pressure correlation in our studies II and V.

In study II we measured the intracapsular pressure with the patient in lateral decubitus position and after the release of the short rotators, whereas Robertsson et al. (1995) measured the pressure before surgery with the patient supine. The hypothesis was raised in study II whether this might influence the pressure differences we found. However, in study V we found that short rotator release did not affect the intracapsular pressure except some increase in 45° of flexion.

Posterior soft tissue repair and capsular distension

In study III we investigated the changes of sonographically measured capsular distance in THA hips with or without posterior soft tissue repair. It has been suggested that the "dead space" with a large amount of fluid which is a common finding during hip revision for recurrent dislocations is the result of the dislocation trauma (Pellicci et al. 1998, McCollum et al. 1990), whereas other authors propose another interpretation, that the "dead space" is in itself the cause of the dislocation (Pellicci et al. 1998). Based on findings by Wingstrand and Wingstrand (1997), enclosed and increased postoperative amounts of free fluid may be one contributing factor in dislocations of the THA hip due to the fact that the stabilizing effect of the atmospheric pressure is eliminated if there is a significant volume of free fluid remaining in the joint.

According to Pellicci et al. (1998) posterior soft tissue repair should eliminate the "dead space" and decrease the amount of fluid in the hip joint. In study III we found the opposite, i.e. increased capsular distension in the posterior soft tissue repair group 6 months after surgery indicating that posterior soft tissue repair resulted in enclosure of a postoperative hematoma and consequently a longer lasting periarticular seroma in the postoperative period.

The anterior capsular distance in the posterior soft tissue repair group decreases with time, as demonstrated by our significantly decreased capsular distension 12 months postoperatively. The majority of postoperative dislocations following THA occur within the first three months postoperatively (Pellicci et al. 1998, Weeden et al. 2003).

Our measurements suggest that posterior soft tissue repair has not eliminated the dead space after 6 months as compared to the non-repaired group. The decreased dislocation rates in previous studies (Pellicci et al. 1998, Weeden et al. 2003) thus could be explained only by the posterior mechanical support. The significant difference in capsular distension at 6 months with and without posterior repair supports the assumption that the soft tissue reattachment is strong enough and remains intact postoperatively. Mihalko and Whiteside (2004) reported that the posterior soft tissue repair can remain intact even if the hip dislocates, whereas, Stahelin et al. 2004 reported that posterior soft tissue repair failed in 15 out of 20 cases 3 months after THA.

Wear and capsular distension

There are several theories on the causes of aseptic loosening in THA. An early theory presented describing the development of aseptic loosening was a "cement disease" theory introduced by Willert (1977). The author analyzed tissue samples taken from newly formed capsules surrounding artificial joints. He found small particles of plastic, metal and acrylic cement in the capsular tissue, and suggested that these particles could initiate a foreign body reaction and formation of granulation tissue. Willert (1977) suggested that this foreign body response could cause osteolysis and subsequent aseptic loosening.

The "PE particle disease" theory was introduced by Howie et al. (1988). In a study in rats a plug of polymethylmethacrylate was inserted into each femur and exposed to ultrahigh-molecular-weight polyethylene particles 2, 4, 6 and 8 weeks after insertion. The aim was to mimic the bone-cement interface in cemented implants. Bone resorption was found around the implant, and at the interface the bone had been replaced by connective tissue. Based on these findings authors postulated that particles alone cause bone resorption in the absence of motion or infection. These results have however not ever been repeated (Howie et al. 1993, Van Der Vis et al. 1997).

Sundfeldt et al. (2002) investigated the effect of repetitive injections of UHMWPE particles in

rabbit knees with a weight-bearing, articulating osseointegrated prosthetic joint. Despite the high load of particles no radiographic, histological or biomechanical differences between test and control groups were detected, and the authors concluded that additional factors are required to initiate the loosening process. Based on these findings increased intraarticular hydrostatic pressure in the THA hip was suggested as an additional factor in the development of aseptic loosening.

The theory of "increased intracapsular fluid pressure", describing the effective joint space and its role in the development of aseptic loosening, was presented by Schmalzried et al. (1992) discussing the effect of high pressure as part of the osteolysis/loosening process. They suggested that intraarticular pressure may act as a mechanical factor also increasing PE wear because of a fluid pumping mechanism releasing abrasive particles (cement or metal), subsequent bone resorption, and subsequently development of aseptic loosening.

Van der Vis and Aspenberg (1998) demonstrated that fluid pressure induced osteolysis and osteocyte death. A titanium surface was applied onto cortical bone in rabbits. A small area under the implant was subjected to a constant fluid pressure of 150 mmHg leading to massive bone resorption under the pressurized area with the formation of granulation tissue replacing parts of the resorbed bone. THA with 32 mm femoral heads had greater sonographically measured capsular distension in our study IV as compared to 28 mm femoral heads ($p < 0.001$). It was also shown that 32 mm femoral heads were associated with higher polyethylene wear and higher cumulative revision rates when compared to 22 mm femoral heads (Kesteris et al. 1996, Tarasevicius et al. 2006). The correlation in our study IV between PE wear, which correlates to loosening after THA (Tarasevicius et al. 2006), and sonographically measured capsular distension indicates that intracapsular fluid pressure has a role in the development of aseptic loosening after THA due to osteolysis. This would be in accordance with the experimental findings by Van der Vis and Aspenberg (1998). However the exact chain of events concerning PE wear, increased intracapsular pressure and osteolysis/loosening is unknown. PE particles may act as a trigger mechanism to start an inflammatory process, leading to the production of

more fluid, increasing the intracapsular pressure as demonstrated with increased capsular distance in our study IV. PE wear and sonographically measured capsular distension were increased in 32 mm heads as compared to 28 mm heads in our study IV

in THA hips with no radiographic signs of loosening. This indicates that increased intracapsular pressure/capsular distension, synovitis and a subsequent loosening process starts long before it can be detected radiographically.

Conclusions

1. Ultrasound examination of the THA hip is a reliable method to measure the anterior capsular distance of the joint capsule, i.e. distension of the joint capsule. It requires experience, however, to achieve sufficient intra-, and interobserver agreement.
2. An increased radiographic severity of OA is correlated to decreased elasticity/compliance of the joint capsule and with decreased intracapsular hydrostatic pressure.
3. Posterior soft tissue repair in THA does not eliminate, but actually increases, the postoperative intraarticular dead space as indicated by an increased anterior capsular distension.
4. 32 mm femoral heads as compared to 28 mm heads is associated with increased sonographically measured capsular distension, linear and volumetric wear in radiographically stable THA hips.
5. Tension in the short rotator tendons does not increase the intracapsular pressure in radiographically severe OA hips, and there is no correlation between pain and intracapsular pressure in late OA stages.

Acknowledgments

I express my sincere gratitude to:

Prof. Hans Wingstrand for his first offer to start this research project in Lund, for being my excellent supervisor and mentor, for being “always available“, and for all support during my work in Lund.

Otto Robertsson, for his very constructive criticism, for all help with complicated statistics and finally for all his time, usually during nights, he spent with me editing the papers.

Uldis Kesteris for his constructive criticism and for all scientific, as well as, non-scientific discussions.

My father, who wrote a letter to Prof. Lars Lidgren

asking about the possibility for a young doctor to come to Lund to learn “something”.

Prof. Lars Lidgren for making my first visit to Lund possible.

My family, Viktorija, Matas and Ausrine, for all support I had during the time I worked on this thesis.

This work was supported by:

Pfizer EU-Articulum Fellowship

Region Skåne

The Faculty of Medicine, Lund University

Stiftelsen för bistånd åt rörelsehindrade i Skåne

The Swedish Research Council-Medicine (09509)

Summary

Ultrasonography as a tool measuring the anterior capsular distance in THA was so far not described nor validated. Comparing the measurements of the capsular distance set with a caliper/ruler with those performed with ultrasonography on a THA model demonstrated a high correlation between measurements. The effect of experience of ultrasonography in THA was also evaluated comparing the first and last series of examinations. It was shown that intra/inter observer agreement increased with increasing number of examinations.

The pain in osteoarthritis (OA) and its relation to the elastic properties of the hip joint capsule was analyzed. In OA patients intracapsular pressure and capsular elasticity, i.e. compliance, was measured. Pain assessment, radiographic evaluation and ultrasonography measuring the anterior capsular distance of the hip joint were performed prior to these pressure measurements. No correlation was found between pain and intracapsular pressure in these OA hips. However, there was an inverse correlation between radiographic severity of OA and elasticity of the hip joint capsule. These findings indicate an increase in intracapsular pressure in early stages of OA and lower or no pressure in late OA. This observed lack of pain/pressure correlation was not in accordance with previous reports. These measurements were performed after the release of the short rotators. To investigate the effect of the short rotators on intracapsular pressure we investigated the pressure, pain and radiographic grade in OA patients. The pressure was measured in various positions of the hip before and after release of the short rotators. Release of the short rotators did not change the intracapsular pressure in any position except in 45° flexion, in which the pressure

increased, nor did we find any correlation between pain and intracapsular pressure.

Dislocation after THA is one of the most common postoperative complications. Postoperative intraarticular edema and/or fluid might be contributing factors. Posterior soft tissue repair was suggested to reduce the dislocation rate and decrease the volume of postoperative fluid in the THA hip. THA patients with or without posterior soft tissue repair were analyzed. To evaluate postoperative capsular distension, indicating synovial edema/fluid, US was performed 6 and 12 months after surgery. Posterior soft tissue repair resulted in greater sonographically measured capsular distance 6 months postoperatively, but after 12 months there was no difference in hips with or without posterior soft tissue repair. This finding suggests that the previously postulated idea that posterior soft tissue repair reduces postoperative “dead space can be debated.

The role of synovitis and increased intracapsular hydrostatic pressure in the loosening process after THA has gained increased attention. Unrevised, radiographically stable hips that had THA because of osteoarthritis 10 years earlier with 28 or 32 mm femoral heads were analyzed. The correlation between PE wear and sonographically measured capsular distances was estimated. It was found that 32 mm femoral heads were associated with greater wear and greater capsular distance as compared to 28 mm heads. A correlation between linear and volumetric wear and sonographically measured capsular distance was also noted. These findings were observed before radiographic signs of loosening, and indicate that the THA loosening process starts before its radiographic appearance.

Summary in Swedish

Ultraljud (US) som verktyg att studera utspänningen av ledkapseln framsida i höfter opererade med ledprotes har hittills inte beskrivits eller utvärderats. På en modell av en inopererad höftsledprotes kunde en god mätnoggrannhet med US avseende detta konstateras och att med ökad erfarenhet ökade snabbt den intraindividuelle precisionen hos undersökaren och den interindividuella överensstämmelsen mellan undersökarna.

Smärtan vid höftledsartros och dess relation till de elastiska egenskaperna hos ledkapseln undersöktes. Det intrakapsulära vätsketrycket i leden och ledkapseln elasticitet mättes. Utvärdering av smärta, röntgenbilder och US-mätning av ledkapseln utspänning gjordes innan det intrakapsulära vätsketrycket mättes. Ingen korrelation kunde konstateras mellan smärta och intrakapsulärt tryck i dessa artrosleder men däremot ett omvänt förhållande mellan röntgenologiskt avancerad artros och ledkapseln elasticitet. Dessa fynd pekar på att det intrakapsulära trycket är större vid tidig artros och mindre eller inget i sena artrosstadier. Tidigare studier har däremot visat på en korrelation mellan smärta och intrakapsulärt tryck. För att studera hur detta påverkas av avlösning av de korta rotatormusklerna vid operationen utvärderades smärta och artrosgrad innan operation samt det intrakapsulära trycket före och efter avlösning av dessa muskler under operationen. Avlösning av de korta rotatormusklerna påverkade inte det intrakapsulära trycket annat än med leden i 45° flexion då trycket ökade, inte heller konstaterades något samband mellan smärta och intrakapsulärt tryck.

Att den konstgjorda leden hoppar ur led är den vanligaste komplikationen. Ökad svullnad i leden och/eller ökad mängd ledvätska kan vara bidragande faktorer. Att reparera de vid operationen avskurna bakre korta rotatormusklerna har tidigare föreslagits kunna minska risken för denna komplikation genom att minimera volymen innanför ledkapseln efter operationen. Med US mättes därför utspänningen av ledkapseln 6 och 12 månader hos två grupper patienter där man i den ena gjorde muskelreparation. En större utspänning av ledkapseln kunde efter 6 månader konstateras i den grupp av patienter där man gjort reparationen men efter 12 månader hade utspänningen i denna grupp minskat till samma nivå som i kontrollgruppen. Detta fynd kan ifrågasätta det tidigare antagandet att muskelreparation minimerar volymen under ledkapseln.

Lossning av de konstgjorda ledkomponenterna är en annan komplikation. Betydelsen av ledhinneinflammation och ökat intrakapsulärt tryck i den process där de konstgjorda ledkomponenterna lossnar har rönt ett ökat intresse. Hos ett antal patienter med röntgenologiskt fortfarande fastsittande ledproteser med 32 resp 28 mm diam ledhuvuden mättes 10 år efter operationen plastslitage och med US utspänningen av ledkapseln. Leder med 32 mm diam ledhuvuden befanns ha ett större plastslitage och större utspänning av ledkapseln än leder med 28 mm diam ledhuvuden. Att detta noteras innan man på röntgenbilden kan se tecken till lossning antyder att lossningsprocessen börjar tidigare än vad röntgen kan påvisa.

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Errata

1. The Results section in the manuscript “Intracapsular pressure and elasticity of the hip joint capsule in osteoarthritis” (Paper II). The correlation between OA grade and symptoms, instead of $r=0.34$, should be $r=0.034$
2. The lines in the Figures 3 and 4 in the manuscript “Intracapsular pressure and elasticity of the hip joint capsule in osteoarthritis” (Paper II) should be deleted.
3. The Results section in the manuscript “Dynamics of hip joint effusion after posterior soft tissue repair in total hip arthroplasty” (Paper III). The word “median” in sentence “The median capsular distension measured in...” should be “mean”. The word “median” in sentence “After 12 months the median capsular distension...” should be “mean”.
4. The Discussion section in the manuscript “Dynamics of hip joint effusion after posterior soft tissue repair in total hip arthroplasty” (Paper III). The word “increased” in the sentence “We found the opposite, i.e. increased capsular distension in the posterior soft tissue repair group six months after surgery.” should be “greater”.
5. The Results section in the manuscript “Short rotator tendons do not increase intracapsular pressure in severe osteoarthritic hips” (Paper V). The legend of table 1 should be “Intracapsular pressure measurements data (means and standard deviations)”. The Authors’ contributions section, the “OT” should be “OR”.