Visualisation of articular motion in orthopaedics
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Clinical applications

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Abstract

This chapter describes the application of the range of motion simulation system presented in Chapter 3, 4 and 5 to three orthopaedic problems. Three case reports are presented, followed by a general discussion. The case reports demonstrate the applicability of the simulation system in orthopaedic decision-making.

The first case concerns a 58-year old female patient who reported in the Emergency Department with a Neer 3-part proximal humerus fracture. Using the range of motion simulation system and a CT scan we analysed the fracture and calculated the correction required to prevent impingement. The fracture was reduced and stabilised by a locking plate, realigning the medialised and internally rotated humeral shaft. Range of motion limitations due to bony impingement visible in the simulations of the pre-operative CT scan had mostly disappeared in the simulations of a post-operative CT scan.

The second case report concerns a 62-year old female patient who had undergone total hip replacement surgery. Eight months after the operation she reported with pain, a constant feel of instability of her replaced hip joint and a ‘clicking’-sound that she heard during movement patterns that included a large abduction angle. Analysis of a CT-scan using the range of motion simulation system revealed that the acetabular cup component was malaligned and caused impingement with respect to the femoral neck, resulting in subluxation. The patient preferred not to undergo revision surgery, but rather prevent the extreme movements she made. She indicated that the range of motion simulations helped her to better understand the problem and to avoid the motion patterns that lead to the subluxation and subsequent discomfort.

The last case report in this chapter describes the technical and clinical results of two consecutive arthroscopic shavings of an osseous cam protrusion in a 50-year old male patient with complaints of femoroacetabular impingement. Twelve weeks after the first arthroscopic shaving, the patient still experienced groin pain. Using the range of motion simulation system the kinematics of the hip joint were analysed. Bone impinging at the hip joint during the range of motion simulations was was removed in a second arthroscopic procedure. Six months post-operatively the patient is almost pain free and has regained range of motion to a functional level.

7.1 Case report 1: Range of motion implications of a proximal humerus fracture

7.1.1 Introduction

Proximal humerus fractures (PHF) have an incidence rate of approximately 73 in 100.000 and are more prevalent in elderly (Lind et al., 1989, Van Staa et al., 2001). Depending on the severity of the fracture, several treatment options are proposed, ranging from conservative treatment to shoulder arthroplasty. The decision is often based on factors such as age and patient expectations, on assessment of radiographs or computed tomography (CT), as well as on the application of different fracture classification systems presented in the literature (Codman, 1934, Neer, 1970, Hertel et al., 2004). However, the classification systems have been much disputed for their reproducibility and effectiveness in predicting outcome (Sidor et al., 1993, Siebenrock and Gerber, 1993).

The implications of treatment decisions, i.e. surgical or conservative treatment, in combination with the subjectivity of the PHF classification systems encouraged us to investigate whether or not a computerised dynamic assessment of the fracture adds to the decision-making process in the treatment of PHFs. A critical aspect in the prediction of outcome of PHFs is the altered (post-trauma) bony morphology, leading to a variety of conditions of which loss of Range of motion (ROM) and persistent pain are most relevant. Both can be related to impingement of bone at the shoulder joint. In this case report we demonstrate the clinical use of our dynamic ROM simulation system in a relative young patient with a Neer 3-part humerus fracture.

7.1.2 Case description

The patient was a 58 years-old, previously healthy woman that fell from her bike. She was presented at the Emergency Department of our hospital with a painful right shoulder. Physical examination revealed a painful, slightly swollen shoulder with ecchymosis. There was no apparent neurovascular injury. The X-ray of her shoulder (see Figure 7.1) showed a 3-part PHF. No other fractures or abnormalities were diagnosed.

In this case radiographs alone could potentially lead to misdiagnosing this fracture as a 2-part PHF with only slight medial displacement of the humeral shaft. The additional use of CT imaging revealed a 3-part fracture with significant medial displacement of the humeral shaft of 23 mm while it was also 38° internally rotated with respect to the humeral head. Additionally, the CT data was loaded into the ROM simulation system that was described in detail in Chapter 3 of this thesis.

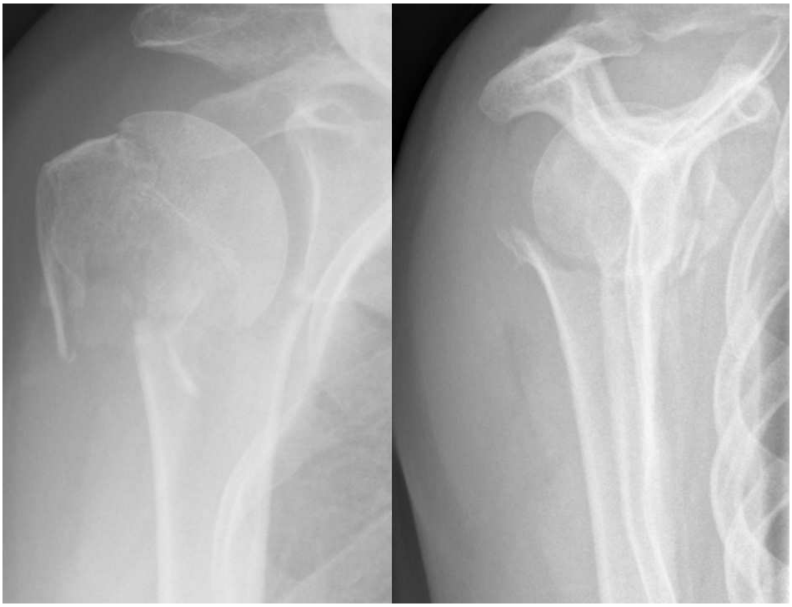

Figure 7.1: Pre-operative AP and lateral radiographs of right shoulder. Only with the use of a CT-scan the 3-part PHF could be fully appreciated.

Pre-operative simulation of ROM, assuming the fracture would have healed in post-traumatic configuration, indicated that the available range of external rotation in 0° of adduction would be limited to only 4° due to the medialisation and rotation of the humeral shaft. According to the ROM simulations the limitation of external rotation would decrease to 0° beyond 45° of abduction, giving rise to the question whether this limitation would create blockade for external rotation. The ROM simulations did not show risk of impingement between the greater tuberosity and the acromial arch (see Figure 7.2).

Initially, it was decided to treat this fracture conservatively, because the predicted deficiency in ROM would not limit activities of daily living. At radiological follow-up, after the first week of immobilisation, secondary displacement of fracture occurred, with further medialisation of the humeral shaft. This deterioration was probably due to muscle pull at the fracture elements by teres minor and pectoralis major muscles. After the secondary fracture displacement it was decided to perform open reduction and internal fixation, using an angular stable locking plate.

Using a deltopectoral approach, the greater tuberosity was reduced and the medialisation and rotation of the humeral shaft were corrected. The reduced fracture

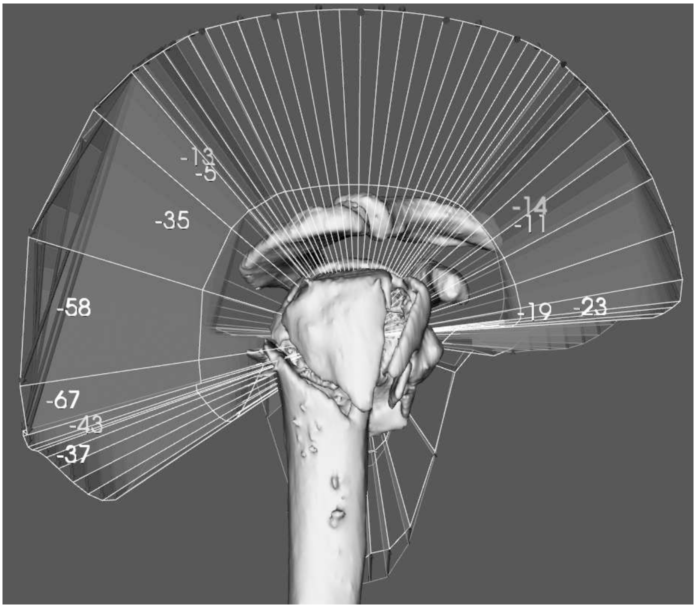

Figure 7.2: Bone-determined ROM simulation using the pre-operative CT data. A comparison is made with ROM simulations of a healthy subject (coloured surfaces and number of degrees). Using this simulation we found a large ROM deficiency for external rotation and a relatively small deficiency for forward flexion. There is no impingement of the tuberosities with the acromial arch.

was fixed with a angular stable locking plate (Litos Tifix, Hamburg, Germany) (see Figure 7.3).

Assisted active forward flexion and circumduction of the shoulder was initiated immediately after surgery. After 2 weeks active physiotherapy was allowed with a maximum forward flexion of 90° and maximum external rotation of 20°. After 6 weeks unrestricted active shoulder training was started.

7.1.3 Results

Post-operatively, ROM simulations indicated that external rotation in 0° of adduction was now limited to 20°. Beyond 20° of abduction no limitation of external rotation was observed. This is shown in Figure 7.4. In accordance with the pre-operative simulations, no impingement of the greater tuberosity occurred in this simulation. Follow-up of fracture healing with plain X-rays showed normal fracture healing without secondary displacement or early signs of avascular necrosis.

Figure 7.3: Post-operative AP and lateral radiographs of right shoulder. Reduction of the greater tuberosity and correction of the medialisation and rotational displacement of the humeral shaft was achieved using an angular stable locking plate.

Twelve weeks post-operatively the following ROM was obtained: active forward flexion was 110°, external rotation in 0° of adduction was 15° and external rotation in 90° of abduction was 30°. Passive ROM revealed no differences in joint mobility between the sound and the healed shoulder.

7.2 Case report 2: Hip prosthesis luxation analysis

7.2.1 Introduction

Dislocation of total hip prostheses is a relatively common complication in total hip arthroplasty. In a study by Phillips et al. the incidence of hip dislocation after primary hip replacement was reported to be 3.9% (Phillips et al., 2003). The risk of dislocation is highest within the first three months and is reduced over a period of one year (Lindberg et al., 1982).

When a dislocation of prosthesis components occurs this may be attributed to the alignment of the prosthesis components, but also to other causes such as cognitive

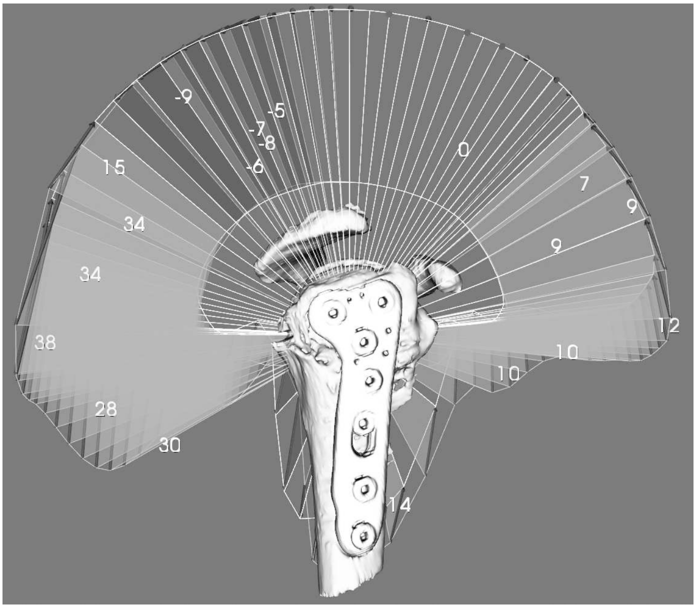

Figure 7.4: Bone-determined ROM simulation using the post-operative CT data. A comparison is made with the pre-operative ROM simulations. Many of the ROM limitations caused by the morphology of the fracture have been alleviated, as depicted by green surfaces. The change of bone-determined ROM ranged is 38° for backward flexion and 12° for forward flexion.

problems of the patient or soft tissue problems. Identification of the reason for dislocation is important, since only in the case of malalignment of prosthesis components a revision operation may prevent further dislocations.

Assessment of prosthesis alignment and its possible cause for hip dislocation is generally performed using static radiographs and CT-scans, even though the dislocation is a dynamic process. In this case report the ROM simulation system is used to dynamically evaluate the risk of dislocation of a hip joint with a total hip prosthesis.

7.2.2 Case description

A 61 -year old female patient reported with greater trochanter and groin pain and a clicking sensation in her artificial hip. She had a total hip replacement 8 months earlier, following the diagnosis of osteoarthritis. When she consulted the clinic she reported that the clicking sensation in the hip occurred spontaneously 6 months after surgery, and was present while rising from a chair, while walking with firms steps

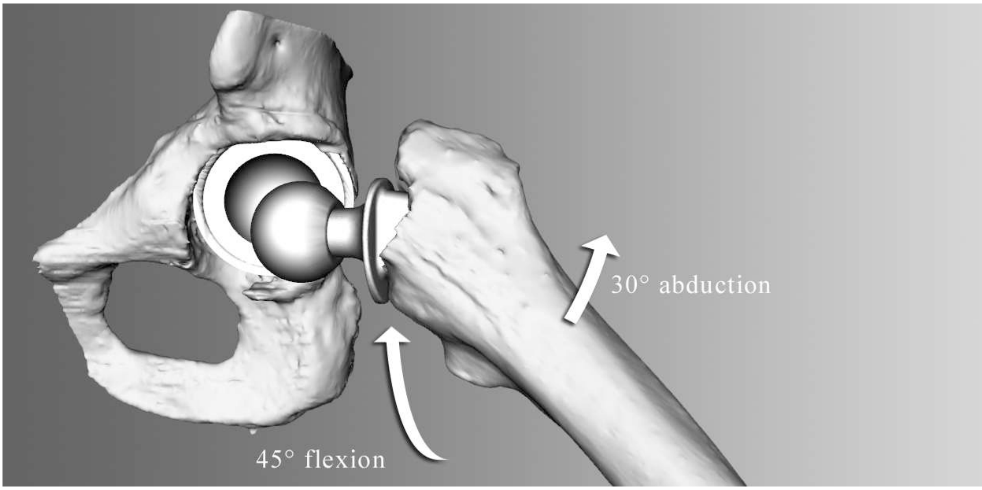

Figure 7.5: ROM simulation of the hip joint. According to the simulations dislocation occurred a combined movement of 45° of flexion and 30° of abduction.

and while doing her Yoga exercises (especially during the Buddha sitting position). During this click, she had an uneasy feeling about her hip. She was active, could walk for an unlimited distance, if the painful clicking did not occur. Professionally, she worked as a teacher. At clinical examination her legs showed equal leg length. The hip excursions were extension / flexion 0° / 120°, abduction / adduction 40°/0°/30° external/ internal rotation 45°/0°/40° degrees respectively. The clicking sound could be reproduced in a combined flexion, abduction and external rotation movement. The patient did not have complaints regarding the contra-lateral joint.

Radiographic analysis using X-ray photographs and CT showed a cup inclination of 65° and 40° of cup anteversion. With the CT data ROM simulation was performed to further assess the risk of luxation of the prosthesis.

7.2.3 Results

Analysis of a post-operative CT-scan using the ROM simulation system confirmed that the acetabular cup prosthesis was malaligned and caused impingement at 45° of flexion and 30° of abduction (see Figure 7.5). The simulations predicted that posterior dislocation would occur beyond a combined movement of 30° of abduction and 45° of flexion.

Although the simulations indicated that some improvement could be gained by repositioning the acetabular cup, the patient did not prefer to have revision surgery.

However, the ROM simulations helped her to better understand the 'mechanical' hip problem, thus she could avoid making the motion patterns that lead to the subluxation of the hip (i.e. the clicking) discomfort.

7.3 Case report 3: Range of motion implications of femoroacetabular impingement

7.3.1 Introduction

In femoroacetabular impingement (FAI), deformations of the femoral head or the acetabular rim lead to bony impingement, resulting in limited hip motion, pain and progressive damage to the labrum. Recent work suggests that FAI may lead to osteoarthritis (Ganz et al., 2003). Although the etiology of FAI is still unclear, a variety of causes are described, such as excessive sporting activities and post-traumatic or congenital deformities (e.g. developmental dysplasia of the hip) (Leunig et al., 2005).

Two types of FAI are recognised; the cam type and the pincer type. When the acetabular rim shows deformations, this is referred to as a pincer type FAI. Cam type FAI refers to deformations of the femoral head. Cam and pincer individually reduce the space for movement and lead to FAI symptoms. The two types are reported to occur simultaneously in 86% of patients (Beck et al., 2005). However, recent evidence indicates that cam and pincer hips are distinct patho-anatomic entities (Cobb et al., 2010). Treatment options vary and include surgical dislocation and arthroscopic surgery. Satisfactory outcome is reported to range from 90% to 100% for arthroscopic management (Larson and Giveans, 2008, Philippon et al., 2009) and from 68% to 80% for open surgery (Beck et al., 2004, Krueger et al., 2007).

Multiple imaging modalities are used for diagnosis and assessment of FAI (Beall et al., 2005, Tannast et al., 2007b, Beaulé et al., 2005, Nötzli et al., 2002). However, these image modalities are static and therefore do not provide sufficient insight in the dynamic spatial relationship of the femoral head and acetabulum. Instead, a dynamic diagnostic approach should be used, such as presented by Tannast et al. (Tannast et al., 2007a).

In the case of a failed primary surgical correction of FAI, the decision whether to perform a second operation is based on considerations regarding the altered expectations of the patient in combination with the limited chance of improvement. In addition, the risk of further weakening the femoroacetabular joint must be assessed, as it has been shown that bone strength is greatly affected when large amounts of bone are removed from the femoral head (Mardones et al., 2005). If the outcome of primary management is unsatisfactorily, this is frequently due to persisting impinge-

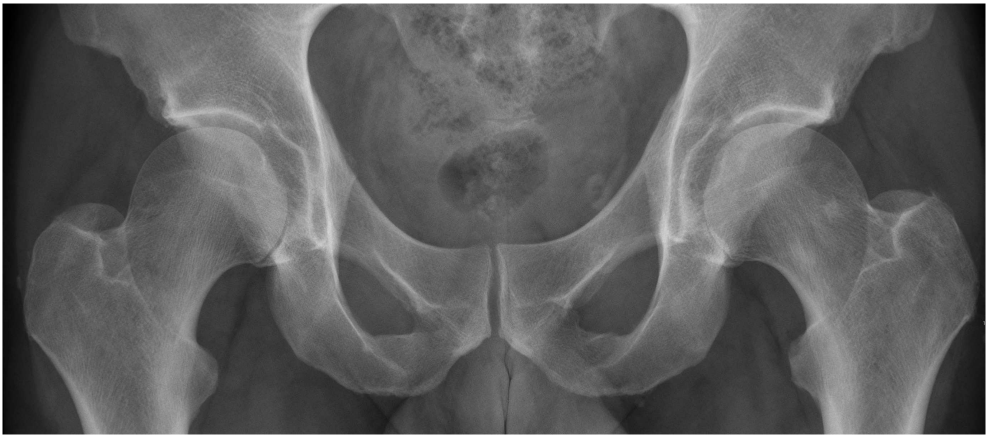

Figure 7.6: Pre-operative AP and lateral radiographs.

ment (Philippon et al., 2007). Additional evaluation instruments may support further treatment decisions.

In this case report the ROM simulator is used to analyse the bone-determined ROM of a hip joint. From this analysis motion patterns that may lead to FAI symptoms for a particular patient can be determined.

7.3.2 Case description

The patient was a 50-year old male with a progressive painful right hip since the last 5 years. Work and sports activities were limited due to the hip pain. Limping became more apparent the last year and pain forced him to stop walking after 5 minutes.

Physical examination revealed pain with rotation in 90° of flexion. Flexion beyond 100° was not possible. Internal rotation was limited to 20°. External rotation was not impaired. The anterior impingement test was positive.

Radiographs unveiled a cam deformity at the medial side of the femoral head and mild degenerative changes on the acetabular side (see Figure 7.6 and 7.7). During arthroscopy the suspected cam lesion was seen, additionally we saw an intact labrum and mild degenerative changes of the cartilage of the antero-lateral part of the acetabulum, Outerbridge classification I-II (Outerbridge, 1961). The cam lesion was shaved off. Partial weight-bearing was allowed directly after surgery, followed by full weight bearing after 6 weeks.

The arthroscopic correction was only marginally successful as pain recurred 12 weeks after surgery. Minimal improvement in daily work and walking distance was

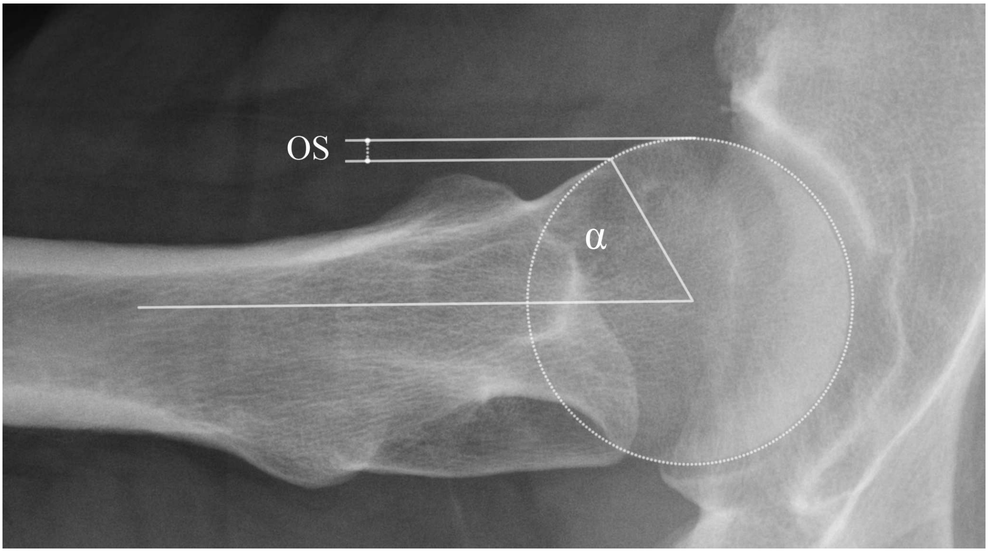

Figure 7.7: Axial view of the femur, showing an increased alpha angle (a = 62°) and decreased head-neck offset (OS).

seen. Using a regular CT scan we determined whether a sufficient portion of the cam protrusion had been shaved off. This seemed to be the case. Subsequently, it was decided to simulate the ROM of the patient in order to gain insight in the kinematics of the joint. Using the ROM simulation system the CT scan of the hip joint was analysed.

According to the simulations the risk of impingement was small in pure flexion and pure abduction. However, 45° of a combined flexion and abduction motion was predicted to lead to impingement (see Figure 7.8). The available range of internal rotation at 90° of flexion was 15°, compared to 35° (±12°) in healthy hip joints as found by Tannast et al.. (Tannast et al., 2007a).

A second arthroscopy of the affected hip was performed during which the remaining osseous rim on the femoral head was shaved off.

7.3.3 Results

Six months after the procedure, the patient is almost pain free and has regained a pain-free functional ROM. Limping had disappeared and he could walk pain-free. Informed consent for a CT scan was obtained for evaluation, in which the ROM simulations showed that impingement was absent (see Figure 7.9 and 7.10).

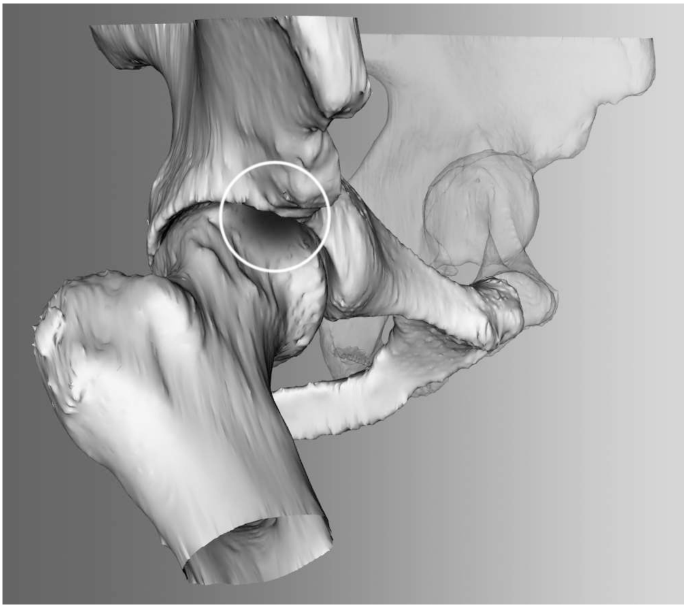

Figure 7.8: ROM simulations of the hip joint. The pose of the femur is adjustable. When impingement is detected, the femur is colored red.

7.4 Discussion

In this chapter, three applications of the ROM simulation system were described, demonstrating its potential as a dynamic assessment tool in orthopaedic decision-making. This new technique may provide the surgeon with a better tool to predict surgical success. Restoration of ROM, besides sufficient pain relief, should play a central role in choosing different treatment modalities. The ability to choose patients that may benefit from surgery in an early stage of the treatment protocol may not only improve functional outcome scores after surgically treatment, but also provide for better informed consent.

There is an ongoing discussion whether or not to operate on three and four-part PHFs especially in the elderly patient as sufficient proof from large prospective randomised clinical trials is still lacking. Functional outcome and patient satisfaction varies greatly and depends on multiple parameters. Important parameters are the amount and direction of displacement and the necessary reduction of fragments during surgery. These are patient-specific parameters and are difficult to determine using static modalities such as radiographs and CT. The described dynamic diagnostic ROM simulation system helps in making the decision for conservative or surgical treatment

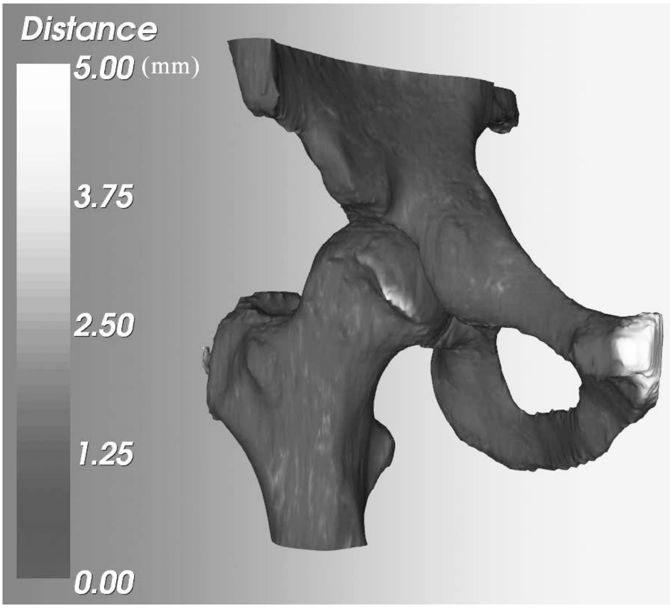

Figure 7.9: Difference in the bone models that are extracted from the CT data before and after the second arthroscopic shaving. This visualisation indicates which part of the femoral head has been shaved off during the second arthroscopy. Point distances are in millimetres. The pubis is highlighted because of a difference in the scanned area.

of a PHF. The simulation of post-trauma function was indicative of functional outcome and supports our claim that the system may be used to facilitate the treatment decision regarding these fractures.

In total hip replacements, revision surgery is demanding for the patient. The decision whether or not to revise a prosthesis should be carefully considered, especially in the case of dislocations where multiple causes can be discerned which are not always related to the interrelation between the femoral head and acetabular cup. In our case we were capable of demonstrating that the simulated risk of dislocation corresponded with the discomfort of the patient and the 'clicking'-sound that was heard during the physical examination. The patient opted not to undergo revision surgery. However, the visual representation of the dislocation was helpful for her and allowed her to understand what motion patterns were causing the discomfort. This indicates that besides supporting treatment decisions, the simulation system can also be used to explain clinical problems to patients.

Our case study on FAI demonstrates the relevance of dynamic assessment when

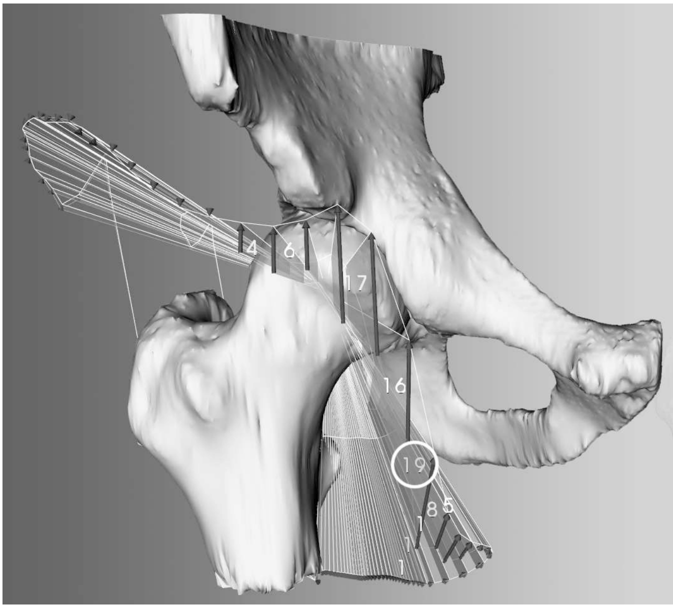

Figure 7.10: ROM simulation results using the post-operative CT scan. This visualisation depicts the outlines of the ROM as constrained by collision between the two bones. The numbers indicate the ROM improvement when compared to the bone models of the pre-operative CT scan. An additional 19° of ROM was gained by further shaving of the femoral head.

outcome of primary arthroscopic management is unsatisfactorily. The ROM simulations may aid clinicians in determining possible gain of a second operation. An important consideration in the decision for further treatment is that re-operation, whether arthoscopically or open, can cause considerable comorbility to a patient. Additional image modalities and simulation instruments that support and justify this decision are beneficial in this matter for both the surgeon and the patient. In the described case the use of simulation software to establish how osseous anatomy disturbs function of the hip joint seems effective.

In conclusion, we believe that the ROM simulations form a promising technique to predict the ROM of articular joints, assuming there is no additional pathology to muscles and nerves. The hypothesis is that it is a helpful tool for choosing between different treatment options. In the future this hypothesis should be tested using a case control study for each of the above applications.