# Noninvasive Three-Dimensional Assessment of Femoroacetabular Impingement

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**ABSTRACT:** A CT-based method ("HipMotion") for the noninvasive three-dimensional assessment of femoroacetabular impingement (FAI) was developed, validated, and applied in a clinical pilot study. The method allows for the anatomically based calculation of hip range of motion (ROM), the exact location of the impingement zone, and the simulation of quantified surgical maneuvers for FAI. The accuracy of HipMotion was $0.7 \pm 3.1^\circ$ in a plastic bone setup and $-5.0 \pm 5.6^\circ$ in a cadaver setup. Reliability and reproducibility were excellent [intraclass correlation coefficient (ICC) > 0.87] for all measures except external rotation (ICC = 0.48). The normal ROM was determined from a cohort of 150 patients and was compared to 31 consecutive hips with FAI. Patients with FAI had a significantly decreased flexion, internal rotation, and abduction in comparison to normal hips ($p < 0.001$). Normal hip flexion and internal rotation are generally overestimated in a number of orthopedic textbooks. HipMotion is a useful tool for further assessment of impinging hips and for appropriate planning of the necessary amount of surgical intervention, which represents the basis for future computer-assisted treatment of FAI with less invasive surgical approaches, such as hip arthroscopy.  J Orthop Res 25:122–131, 2007

**Keywords:** femoroacetabular impingement; range of motion; simulation; three-dimensional computed tomography

## INTRODUCTION

Femoroacetabular impingement (FAI) is a major cause of early osteoarthritis of the hip.[1–3] It is characterized by a repetitive abnormal contact between bony prominences of the antero-superior femoral head-neck junction and/or the acetabular rim during the end range of motion (ROM). Two types of FAI are described. *Pincer* impingement occurs when direct linear contact occurs between the neck and a localized (so-called acetabular retroversion) or generally overcovered acetabulum (so-called protrusio, coxa profunda).[4,5] *Cam* impingement is caused by jamming a nonspherically shaped femoral head-neck junction into the acetabulum.[6] Typical findings during physical examination are restricted internal rotation and reproducible pain with forced internal rotation in 90° of flexion ("impingement sign"[7,8]).

Treatment for FAI is hampered by surgeons' inability to assess the presence, location, and severity of impingement and by the lack of objective methods for planning and executing any proposed treatment. A noninvasive assessment method is essential for improved understanding, accurate diagnosis, and appropriate treatment recommendations.

To address this problem, a computer-assisted noninvasive method for the simulation of individual FAI was developed. The following questions were investigated: (1) How accurate, reliable, and reproducible is the developed simulation? (2) What is the osseous femoroacetabular ROM in asymptomatic patients without anatomical abnormalities? (3) What is the osseous femoroacetabular ROM in patients with FAI? It was hypothesized that patients with FAI have a decreased ROM in terms of flexion and of internal rotation in 90° of flexion.

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## MATERIALS AND METHODS

### Software Development and Validation

The software HipMotion was developed to perform a computed-tomography (CT)-based three-dimensional (3D) kinematics analysis of a hip joint. Based on a CT-scan of the pelvis and the femoral condyles, HipMotion reconstructs a 3D model of the pelvis and the femur and calculates the native preoperative osseous ROM until contact or interference at the impingement point. Soft tissue tension was not simulated. The acetabular and femoral location of impingement is identified (Fig. 1), and simulation of the postoperative hip motion after virtual quantified surgical acetabular and femoral reshaping is performed (Fig. 2), that is, recontouring the hip joint to delay impingement until later in the motion cycle. For accurate angle calculation, two anatomically based reference coordinate systems are defined on the individually reconstructed 3D pelvic model (Fig. 3). The pelvic reference is the anterior pelvic plane (APP), defined by both anterior superior iliac spines and the pubic tubercles.[9,10] On the femoral side, the mechanical axis is given by the hip and knee centers, and the posterior aspects of the femoral condyles are used to set the coronal femoral reference.[11] The center of the femoral head is considered to be the center of rotation.

In the first part of the study, software validation was performed by comparing the virtually predicted with the real, measured ROM by means of an image-free computer navigation system for total hip arthroplasty (Image-Free Hip Version 1.0; BrainLAB, Heimstetten, Germany). A total of 27 hips were used for validation, including 13 normal plastic hips (pelvis item #1301, femur #1129-21; Sawbones, Vashon, WA) and 14 fresh cadaver hips. To ensure a concentric joint and compensate for the lack of cartilage, the plastic acetabula were prepared with felt pads (Fig. 4). This step was necessary for the kinematics calculation of the hip joint center described later. Thirteen to sixteen pads with a thickness of 2.5 mm were used per acetabulum. None of the cadaver hips showed major osteoarthritic changes, and all had preserved concentric joint morphology.

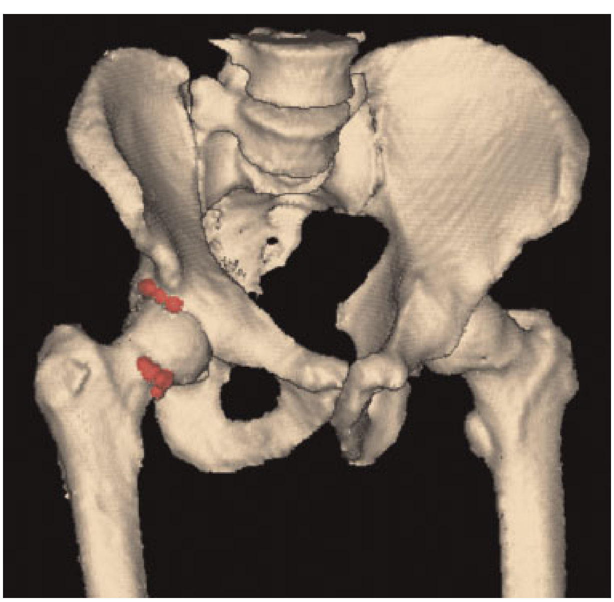

**Figure 1.** The software HipMotion predicts the acetabular and femoral sources of impingement.

Prior to measurement, CT scans of plastic and cadaveric hips including the distal parts of the femora were performed, and the virtual ROM was calculated with the software. Then, two dynamic reference bases were rigidly fixed to the pelvis and the femur (Fig. 4). The four anatomical landmarks of the APP were dissected and digitized with a tracked pointer. The hip center was calculated. Using the position of the reference base in space derived from the movement of the tracker as the surface of a sphere, the 3D center of rotation (corresponding to the center of the head rotating in the acetabulum) was calculated.[12] Because the knee center could not be digitized directly, the femoral epicondyles were recorded, and their midpoint defined to represent the center. By direct manipulation of the hip under the control of an optoelectronic camera, the real ROM was determined and compared to the predicted values. Flexion/extension, abduction/adduction, and internal/external rotation in 90° of flexion were assessed for the plastic bones; flexion and internal rotation in 90° of flexion were assessed for the cadaver hips. All navigation measurements were performed twice by one observer (M.T.).

Because the anatomical landmarks and the acetabular rim had to be defined manually on the 3D pelvic model, the intra- and interobserver variance in detecting ROM was analyzed. Forty consecutive pelvic CT scans were randomized and blinded from the available control and study groups described later and were analyzed twice by two independent observers (M.T., M.K.-L.). The time between measurements was at least 4 weeks. The ROM was calculated, and intra- and interobserver variances were compared.

### Clinical Pilot Study

With Institutional Review Board (IRB) approval, the ROM of 150 normal (control group) and 31 impingement hips (study group) was analyzed and compared with the help of the developed software. For the control group, the contralateral hip of a patient series undergoing CT-based navigated total hip replacement was investigated retrospectively. Height, weight, pain, and functional status of the unaffected side, as well as an anteroposterior (AP) pelvis radiograph were available. AP pelvic radiographs had been obtained with the subject supine with internally rotated lower extremities to compensate for femoral neck anteversion and allow for accurate measurements of the projected neck-shaft angle. The center of the beam had been directed just above the pubic symphysis. Painful hips and hips with osseous abnormalities indicating osteoarthritis or FAI were excluded from the control group. Exclusion criteria are given in Table 1.

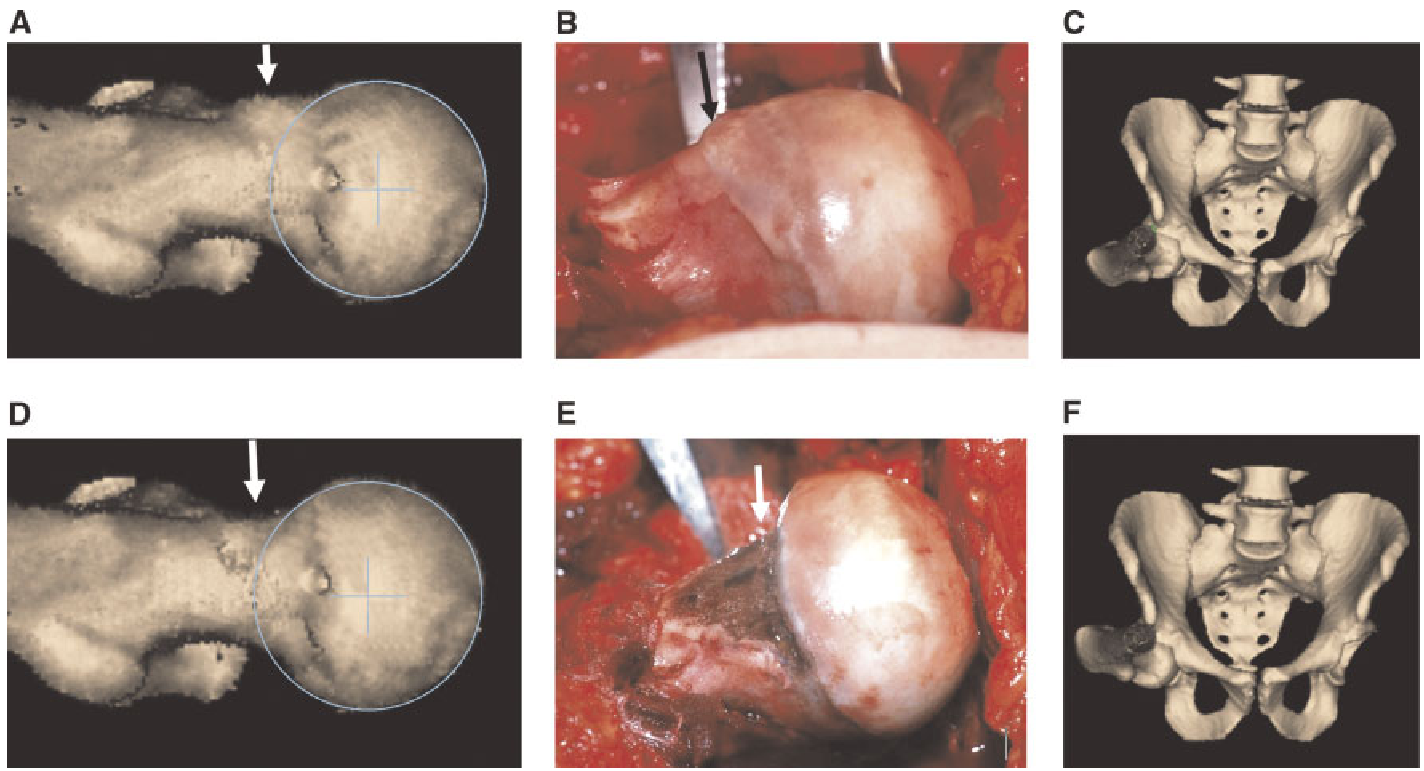


**Figure 2.** The virtual resection of the aspherical part of the femoral head-neck junction (cam impingement, A and D) and the corresponding intraoperative photographs (B and E). The 3D ROM analysis is shown. The native internal rotation in 90° of flexion is 11° (C); after virtual offset creation the internal rotation increased to 37° (F).

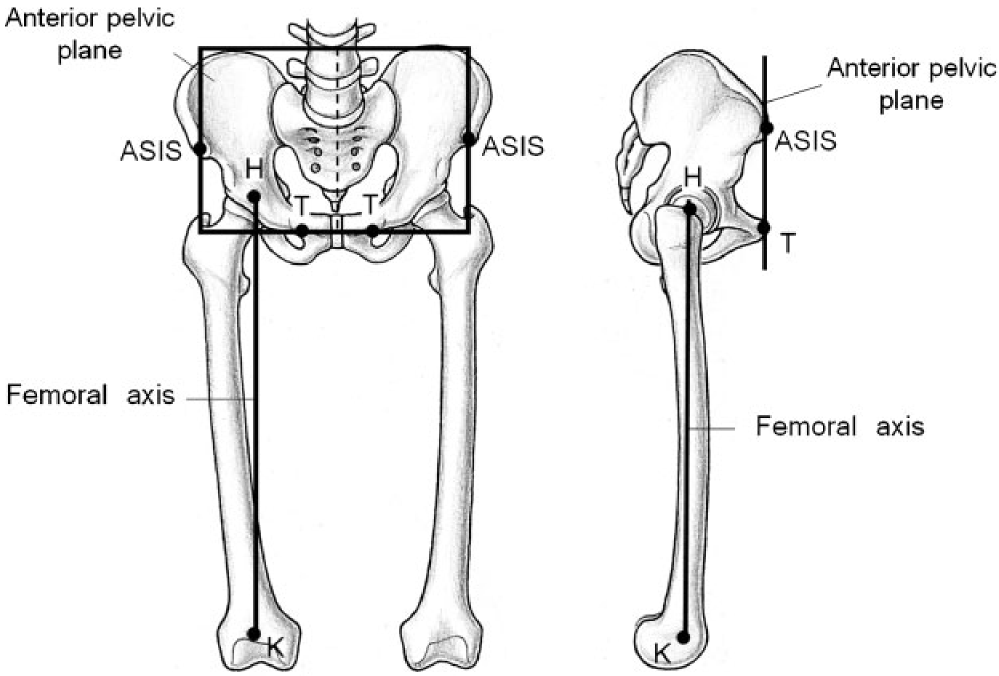


**Figure 3.** Definition of the pelvic and femoral reference coordinate systems and illustration of the neutral orientation (ASIS, anterior superior iliac spines; T, pubic tubercle; H, hip center; K, knee center).

For the study group, 31 consecutive hips (21 patients, 10 bilateral) with FAI were recruited prospectively from the outpatient clinic of one of the authors (S.B.M.). Diagnosis was based on previously described clinical and radiographical criteria for FAI.[1,2] To describe the hip morphology of the study and the control groups, a series of radiographic parameters were assessed by one examiner (M.T.). The definitions of the assessed parameters and their measurement techniques are listed in Table 2. Acetabular pathomorphologies were assessed on the AP pelvic radiograph. Because lateral crosstable radiographs were unavailable for the nonaffected side of the control group, femoral osseous deformities indicating cam impingement were assessed on a reconstructed CT plane parallel to the neck shaft angle and through the center of the femoral head according to the MRI technique of Nötzli et al.[13] The femoroacetabular ROM of each hip was then calculated and compared for the study and control groups.

### Statistical Analysis

Normal distribution was determined with the Kolmogorov-Smirnov test. Paired and unpaired Student's *t*-tests were used for comparison of normally distributed data.

The Wilcoxon rank sum and the Mann-Whitney-*U*-tests were used when comparing paired and nonpaired data without normal distribution. The Kruskal-Wallis test was performed to detect any differences among the different impingement types. To assess associations between categorical variables, Fisher's exact test was performed. Significance was defined as a $p < 0.05$. Intra- and interobserver variance in detecting ROM were assessed using intraclass correlation coefficients (ICC) with: ICC $< 0.20$ for slight agreement; 0.21–0.40 for fair agreement; 0.41–0.60 for moderate agreement; 0.61–0.80 for substantial agreement; $>0.80$ for almost perfect agreement.[14]

## RESULTS

The mean error between two measurements of ROM with the navigation system was $0.3 \pm 2.2^\circ$ (range, $-4$ to $5^\circ$) with an ICC of 0.99. Software validation with the Sawbones revealed an accuracy of $-0.7 \pm 3.1^\circ$ (range, $-9$ to $6^\circ$) for all 78 measured angles. Software validation with the cadaver hips revealed an accuracy of $-5.0 \pm 5.6^\circ$ (range, $-19$ to $7^\circ$). The accuracy of angle detection did not vary for the different motions either for plastic bones ($p = 0.10$, Kruskal-Wallis-test) or for cadaveric hips ($p = 0.28$, Mann-Whitney-*U*-test). Intra- and interobserver measurements were excellent for all motions except external rotation in $90^\circ$ of flexion, where only a moderate agreement could be found for the interobserver ICC (Table 3).

Based on the established exclusion criteria, 114 of the 150 patients of the control group were excluded (Table 1), leaving 36 patients for the determination of normal femoroacetabular ROM.

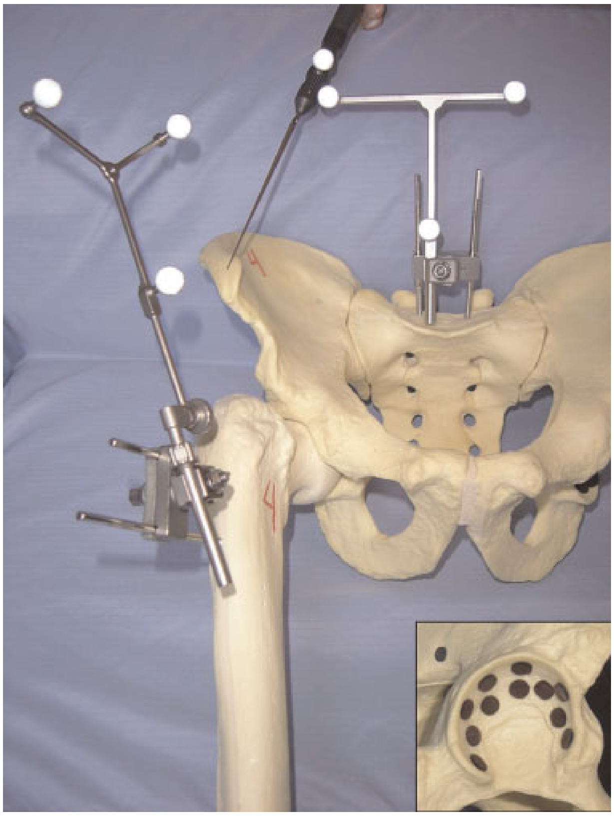

**Figure 4.** The setup for the validation of HipMotion. A dynamic reference base is fixed rigidly both to the femur and pelvis. The reference landmarks are digitized with a tracked pointer. To ensure a concentric joint motion for the Sawbone hips, the acetabulae were prepared with pads (inset).

**Table 1.** Exclusion Criteria for the Control Group[a]

| Exclusion Criteria | Number of Excluded Hips (Total $n = 114$) | Percentage |
|---|---|---|
| Medical history | | |
| Total hip replacement | 9 | 8 |
| Pain | 3 | 3 |
| Previous hip surgery | 3 | 3 |
| Conventional radiographic criteria | | |
| Osteoarthritis > grade 0 | 40 | 35 |
| LCE <25° | 24 | 21 |
| Pistol-grip deformity | 13 | 11 |
| Coxa profunda | 11 | 10 |
| 120° < neck shaft angle <140° | 1 | 1 |
| Acetabular retroversion | 4 | 4 |
| Protrusio acetabuli | 2 | 2 |
| CT measurements | | |
| α-angle <50° | 3 | 3 |
| Femoral retrotorsion | 1 | 1 |

[a] $n = 150$.

The impingement group consisted of 12 cam, seven pincer, and 12 combined pathologies. Demographic data of the study and control groups are compared in Table 4. Patients of the control group were significantly older. Although impingement patients were significantly taller, no difference existed in weight or body mass index (BMI). There was a predominance of male patients in the impingement group. Analysis of the radiographic parameters revealed a significantly smaller extrusion index and a higher incidence of herniation pits in the study group (Table 4). The other radiographic criteria were not significantly different. No difference in normal ROM was found for any motion between men and women in the control group.

Patients with FAI had a significantly decreased flexion, internal rotation in 90° of flexion, and abduction (Table 5). No difference could be found for extension, adduction, or external rotation in 90° of flexion. When comparing the impingement subgroups (cam, pincer, and combined), pure cam and pincer hips had significantly decreased abduction compared to combined pathologies. In addition, cam hips revealed a significantly higher extension and extension in 90° of flexion. No differences were found for flexion, adduction, or internal rotation in 90° of flexion (Table 6).

When comparing only cam with pincer hips, a significantly higher extension was found for the cam subgroup ($p = 0.005$). Although a trend existed towards less flexion for pincer hips ($p = 0.08$), it was not significant. The remaining motions did not differ between these two subgroups.

## DISCUSSION

Femoroacetabular impingement is a pathological condition of the hip joint where repetitive contact between bony prominences of the acetabulum and/or the femoral head-neck junction leads to early degenerative changes. Typically, diagnosis and treatment of FAI are based on a positive correlation among symptoms, physical findings on examination, and suggestive 2D radiographs. Confirmation of the presence of specifically oriented pathoanatomy predisposing to the dynamic states of FAI is very difficult to achieve with 2D reconstructions, even with special radial sequences around the femoral neck axis with MRI. Recently, 3D computed tomography was proven to

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**Table 2.** Definitions of the Measured Radiographic Parameters

| Parameter | Definition | Author | Radiographic Means | Normal Value |
|---|---|---|---|---|
| Lateral center edge angle | Angle formed by a line parallel to the longitudinal pelvic axis and by the line connecting the center of the femoral head with the lateral edge of the acetabulum according to Wiberg | Wiberg et al.[21] | AP pelvic radiograph | $>25^{\circ}$[26] |
| Radiographic grade of osteoarthritis | Grading system according to Tönnis | Tönnis[22] | AP pelvic radiograph | Grade 0[29] |
| Acetabular index | Angle formed by a horizontal line and a tangent from the lowest point of the sclerotic zone of the acetabular roof to the lateral edge of the acetabulum | Tönnis et al.[23] | AP pelvic radiograph | $<10^{\circ}$[30] |
| ACM angle | Angle constructed by different points on the acetabular rim indicating the depth of the acetabulum (exact construction of the angle see reference) | Idelberger and Frank[24] | AP pelvic radiograph | $39^{\circ} < \text{ACM} < 51^{\circ}$[31] |
| MZ distance | Distance between the centers of the femoral head and the socket | Tönnis[22] | AP pelvic radiograph | <6 mm |
| Protrusio acetabuli | The femoral head overlaps the ilioischial line medially | Beck et al.[25] | AP pelvic radiograph | No protrusio |
| Coxa profunda | The floor of the fossa acetabuli touches the ilioischial line | Beck et al.[25] | AP pelvic radiograph | No coxa profunda |
| Acetabular retroversion | The anterior rim runs more laterally in the most proximal part of the acetabulum and crosses the posterior rim distally | Reynolds et al.[4] | AP pelvic radiograph | No retroversion |
| Extrusion index | Percentage of uncovered femoral head in comparison to the total horizontal head diameter | Murphy et al.[26] | AP pelvic radiograph | Unknown |
| Neck shaft angle | Angle formed by the axis of the femoral neck and the proximal femoral diaphyseal axis | Tönnis[22] | AP pelvic radiograph | $125^{\circ} <$ neck shaft angle $<135^{\circ}$[32] |
| Herniation pit | Round to oval radiolucency surrounded by a thin zone of sclerosis in the proximal superior quadrant of the femoral neck | Pitt et al.[27] | AP pelvic radiograph | No herniation pit |
| Femoral antetorsion | Angle between the femoral neck axis through the center of the base of the femoral neck and the condylar axis | Murphy et al.[11] | CT of pelvis and distal femur | No retrotorsion |
| Hip value | Value calculated with the ACM angle, the MZ distance, and the lateral center angle according to Tönnis | Tönnis[22] | AP pelvic radiograph | 6–16 |
| Pistol grip deformity | Aspherical configuration of the femoral head-neck junction in the lateral aspect of the femoral head | Goodman et al.[28] | AP pelvic radiograph | No pistol grip deformity |
| α-angle | Angle formed by the femoral neck axis and a line connecting the center of the femoral head with the point of beginning asphericity | Nötzli et al.[13] | 3D CT of distal femur (crosstable lateral view) | $<50^{\circ}$[13] |

**Table 3.** Results of the Reliability and Reproducibility Study

| Angle | Intra-CC First Rater | Intra-CC Second Rater | Inter-CC | Cronbach's Alpha |
|---|---|---|---|---|
| Flexion | 0.99 | 0.96 | 0.87 | 0.96 |
| Extension | 0.97 | 0.98 | 0.90 | 0.97 |
| Adduction | 0.96 | 0.99 | 0.95 | 0.99 |
| Abduction | 0.97 | 0.96 | 0.94 | 0.99 |
| Internal rot in 90° flex | 0.97 | 0.97 | 0.95 | 0.99 |
| External rot in 90° flex | 0.93 | 0.88 | 0.48 | 0.78 |

represent an accurate tool to assess pathoanatomical abnormalities of the hip for FAI visualization.[15] In addition, CT with 3D surface rendering can provide a virtual reality representation of the pathoanatomy of the hip for both the surgeon and the patient.

The present study describes the development, validation, and clinical pilot application of HipMotion, software for kinematics analysis of 3D hip joint motion. The validation study demonstrated that the calculation of ROM is accurate and reliable for all motions except for external rotation, where only moderate reliability could be found. Using the software, we demonstrated that hips with FAI have a significantly decreased ROM in terms of flexion, internal rotation in 90° of flexion, and abduction.

Our method has limitations. HipMotion is not applicable for largely dysplastic hips with a shallow acetabulum where an unambiguous center of rotation cannot be found. In addition, it cannot be used for hips with advanced osteoarthritis because joint space narrowing leads to a change in the femoral head center relative to the acetabulum, resulting in a nonconcentric joint morphology. In these hips, motion does not only consist of a pure rotation, but also of additional translation, which is difficult to predict and simulate. Murphy et al.[2] showed that advanced osteoarthritis with joint space narrowing is a relative contraindication for surgical correction of FAI. In these hips, cartilage damage is too advanced and even surgical elimination of the impinging source cannot stop the ongoing disease process. In the initial phase when performing surgery remains worthwhile and when a virtual simulation of hip motion and joint-preserving surgery is of great interest, the joint space is still preserved even though substantial preradiographic defects of the joint cartilage already exist.[16] Therefore, application of HipMotion with femoroacetabular impingement is not jeopardized by this limitation.

Another limitation is that the software calculates only the osseous restricted ROM, ignoring cartilaginous structures or soft-tissue contractures or masses for the calculation of ROM. This may explain why the predicted ROM was generally overestimated in the cadaver series. However,

**Table 4.** Comparison of Demographic and Radiographic Data of the Study and Control Groups

| Demographic Parameter | Control Group ($n = 36$) | Impingement Group ($n = 31$) | $p$ value |
|---|---|---|---|
| Age (years) | 53.7 ± 11.3 (24.5–73.5) | 31.1 ± 9.4 (19.1–48.8) | <0.001 |
| Height (cm) | 170 ± 10 (1.58–1.95) | 176 ± 7 (155–188) | 0.008 |
| Weight (kg) | 80.3 ± 17.3 (48.6–115) | 86.4 ± 17.3 (52–127) | 0.161 |
| BMI (kgm$^{-2}$) | 27.6 ± 4.4 (19.6–39.1) | 27.8 ± 4.7 (19.1–37.1) | 0.789 |
| No. of men (% male) | 23 (64) | 27 (87) | 0.027 |
| No. of right hips (% right) | 15 (42) | 17 (54) | 0.203 |
| Lateral center edge angle (degrees) | 31.7 ± 4.8 (24.9–33.2) | 34.4 ± 10.5 (16.8–70.3) | 0.174 |
| Neck shaft angle (degrees) | 130.1 ± 4.5 (122–140) | 131 ± 5.8 (121.2–146.4) | 0.495 |
| Acetabular index (degrees) | 6.0 ± 3.9 (−6.1–12.8) | 5.9 ± 4.4 (0.0–15.4) | 0.860 |
| Femoral antetorsion (degrees) | 20.0 ± 7.7 (6.5–39.1) | 19.1 ± 10.16 (−0.3–35.4) | 0.666 |
| MZ distance (mm) | 1.6 ± 0.8 (1.6–3.9) | 1.7 ± 0.7 (0.7–3.2) | 0.589 |
| ACM angle (degrees) | 44.5 ± 2.9 (37.5–50.7) | 44.3 ± 3.4 (38.0–53.6) | 0.815 |
| Hip value | 8.7 ± 2.0 (6.0–12.5) | 7.6 ± 3.4 (1.2–17.5) | 0.089 |
| Extrusion index (%) | 22.5 ± 4.6 (11.6–32.7) | 19.03 ± 7.6 (0.0–34.6) | 0.029 |
| Herniation pits (%) | 8.3 | 35.4 | 0.007 |

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**Table 5.** Comparison of Range of Motion in Normal and Impingement Hips

| Angle [°] | Normal Group ($n = 36$) | Impingement Group ($n = 31$) | $p$ value |
|---|---|---|---|
| Flexion | 121 ± 11.8 | 105 ± 16.1 | <0.001 |
| Extension | 58 ± 20.4 | 60 ± 31.6 | 0.694 |
| Abduction | 63 ± 11.1 | 51.9 ± 12.1 | <0.001 |
| Adduction | 33 ± 11.9 | 34 ± 12.6 | 0.816 |
| Internal rotation in 90° of flexion | 35 ± 12 | 11.7 ± 7.1 | <0.001 |
| External rotation in 90° of flexion | 101 ± 14.7 | 83.1 ± 33.1 | 0.132 |

**Table 6.** Comparison of Range of Motion among the Impingement Subgroups

| Angle [°] | Cam ($n = 12$) | Pincer ($n = 7$) | Combined ($n = 12$) | $p$ value |
|---|---|---|---|---|
| Flexion | 111 ± 18.0 | 97 ± 9.4 | 103 ± 14.3 | 0.124 |
| Extension | 86 ± 29.7 | 44 ± 23.1 | 45.1 ± 20.4 | 0.001 |
| Abduction | 47 ± 13.1 | 48 ± 9.1 | 59 ± 9.7 | 0.007 |
| Adduction | 41 ± 14.2 | 31 ± 10.0 | 29.1 ± 9.4 | 0.121 |
| Internal rotation in 90° of flexion | 10 ± 6.0 | 11.6 ± 9.1 | 14 ± 7.1 | 0.527 |
| External rotation in 90° of flexion | 99 ± 26.7 | 77 ± 37.0 | 72 ± 32.0 | 0.040 |

direct intraoperative visualization could prove that flexion and internal rotation are limited by bony contact in hips with FAI.[1]

Our results describing normal ROM match well with the data presented in clinical original reports (Table 7). However, comparing these results to guidelines from orthopedic textbooks or other published reports and keeping in mind that our simulation generally overestimates the ROM (about 5°), the normal hip ROM in terms of flexion and internal rotation is overestimated in a considerable number of textbooks.

To the authors' knowledge, there are four reports describing computer-assisted measurements of hip ROM with a simulated hip joint motion. Richolt et al.[17] used a computational model for simulating ROM of hips with slipped capital femoral epiphysis, which was applied prospectively to a single hip without a control group or a thorough validation of the method. Sugano et al.[18] used a CT-based simulation for determining individual hip motion and impingement points and found results similar to those of our study. However, they did not define a reference coordinate system with a definition of the neutral hip joint orientation. Moreover, no description was provided of FAI-related exclusion criteria such as missing femoral head-neck offset or acetabular retroversion in the cranial part of the

**Table 7.** Hip Range of Motion Reported in Literature

| Author | Type of Publication | Type of Measurement | Anatomical Referencing | Flexion (Degrees) | Internal Rotation (Degrees) |
|---|---|---|---|---|---|
| AAOS[33] | Textbook | Clinical | No | 120.3 ± 8.3 | 33 ± 8.2 |
| Adler et al.[34] | Textbook | Clinical | No | 120 | 45 |
| Booher et al.[35] | Textbook | Clinical | No | 120 | 35 |
| Dahmer[36] | Textbook | Clinical | No | 130 | 30–40 |
| Debrunner[37] | Textbook | Clinical | No | 140 | 45 |
| Füessl et al.[38] | Textbook | Clinical | No | 130 | 30–45 |
| Garvin et al.[39] | Textbook | Clinical | No | 135 | 40 |
| Ahlberg et al.[40] | Original article | Clinical | No | 130.8 ± 14.0 | 36.7 ± 12.2 |
| Boone et al.[41] | Original article | Clinical | No | 122.3 ± 6.1 | 47.3 ± 6.0 |
| Roaas et al.[42] | Original article | Clinical | No | 120.3 ± 8.3 | 32.6 ± 8.2 |
| Sugano et al.[18] | Original article | Computer assisted | No statement | 127.4 (110–149)[a]<br>117.4 (84–138)[b] | 47.1 (21.0–69.2)[a]<br>29.5 (2.6–60.5)[b] |
| Current study | Original article | Computer assisted | Yes | 121 ± 11.8 | 35 ± 12 |

[a]Women.
[b]Men.

acetabulum. Their patient cohort (20 men and 20 women) included several impingement hips, which is supported by the fact that the authors found a decreased head-neck ratio in male patients, indicating cam impingement. Last but not least, they included patients with femoral retrotorsion. This reflects the fact that they found decreased flexion and internal rotation in 90° of flexion in the males. The analysis of the present study excluded pathoanatomies indicating cam impingement, and no gender-dependent difference was found.

Ito et al.[19] described and Kang et al.[20] presented an MRI-based computational model for the assessment of hip joint ROM. Unfortunately, Ito et al. did not describe a pelvic or femoral coordinate system, and both of them failed to validate their system or apply it in a patient cohort study. To the authors' knowledge, the present study for the first time compares ROM of normal and impinging hips with the help of a validated computerized method based on strict anatomical references.

In summary, the presented method provides a reliable, accurate, noninvasive clinical tool for the assessment and treatment planning of hip impingement. In the future, this method can be incorporated into surgical navigation systems so that the execution of the surgery itself is accurate. Ultimately, it may be possible to execute the operative treatment with less invasive surgical approaches or even percutaneously with arthroscopy under the guidance of a computer navigation system, substantially reducing morbidity, facilitating recovery, and making the surgery a more logical and reasonable intervention for the prevention of osteoarthrosis of the hip.

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