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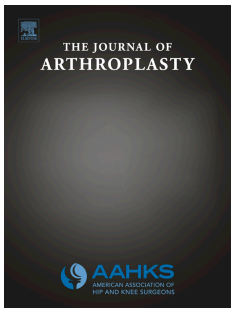

Acetabular morphology predicts the risk of dislocation following hemiarthroplasty for femoral neck fractures in the elderly

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Acetabular morphology predicts the risk of dislocation following hemiarthroplasty for femoral neck fractures in the elderly

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ABSTRACT

Background Hip hemiarthroplasty dislocation is a devastating complication. Among other preoperative risk factors, acetabular morphology has been rarely studied. The purpose of the study was to evaluate the influence of preoperative native acetabular morphology on hemiarthroplasty dislocation.

Material and Methods We retrospectively reviewed 867 patients who underwent hip hemiarthroplasty for femoral neck fracture between January 1, 2014 and January 1, 2019. The 380 patients were treated with an anterior-based muscle-sparing approach. Central-Edge Angle (CEA) and Acetabular Depth-to-Width Ratio (ADWR) of the fractured hip were measured pre-operatively on the antero-posterior (AP) pelvic view. Receiver Operating Characteristic (ROC) curves were performed to analyze the optimal cut-off for CEA and ADWR. Hemiarthroplasty dislocation occurred in 18 patients (4.7%) and the remaining 362 were used as the control group.

Results.

No significant differences in terms of sex, age, dementia, neuromuscular disease, and body mass index (BMI) were found between the 2 groups. The 18 patients who had a hip dislocation had significantly smaller mean CEA than the control group (*p=0.0001*) (mean 36.1±7.5° and 43.2±5.6°, respectively) as well as ADWR (mean 34±6 vs 37±4, respectively) (*p=0.001*). Using the ROC analysis, we report significant cut-offs of 38.5° for CEA (*p=0.0001*) and 34.5 for the ADWR (*p=0.017*).

Conclusions Higher rates of hemiarthroplasty dislocation were observed in patients who had a preoperative CEA of less than 38.5° and an ADWR of less than 34.5. Patients who have preoperative acetabular morphological risk factors for dislocation might be better candidates for a total hip arthroplasty.

Keywords: Acetabular Depth-to-Width ratio, Center-Edge angle, Dislocation, Femoral neck fracture, Hemiarthroplasty, Preoperative Radiographs. Risk factors.

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INTRODUCTION

Femoral neck fractures are one of the most common orthopaedic fractures in the elderly population, affecting patients' mobility and causing complications that may lead to a high mortality rate [1]. They account for a quarter of all fractures worldwide in patients aged 75 years and over [2,3], with a global incidence targeted to reach 6.3 millions in 2050 [4]. The surgical treatment options include internal fixation, hemiarthroplasty, or total hip arthroplasty (THA) according to the type of fracture and patients' characteristics [5]. Hemiarthroplasty is usually performed in the frail and elderly population, while a THA is recommended in the more active population, as it can provide better functional outcome [6]. Data from the current Danish, Swedish, and English registers reported that around 90% of intracapsular displaced neck fractures are treated with a hemiarthroplasty [7-9]. Among the complications after hemiarthroplasty, dislocation is rare, but carries a substantial impact on morbidity and quality of life, contributing to an increased mortality rate [10,11]. The risk of dislocation may be related to different factors classified as patient factors, surgical factors, and morphological factors, which are still debated in the literature [11-15]. An increased risk of dislocation has been mainly reported for the postero-lateral surgical approach [16,17]. Some authors [1,18] investigated the morphological risk factors for instability following bipolar hemiarthroplasty in patients who have femoral neck fractures, performing the measurements on the affected hip post-operatively.

The first aim of this study was to evaluate the Center-Edge Angle (CEA) and the Acetabular Depth-to-Width ratio (ADWR) on pre-operative radiographs as risk factors for instability following bipolar hemiarthroplasty. We excluded the dislocation risk related to the postero-lateral surgical approach analyzing the patients treated by an anterior-based muscle sparing (ABMS) approach. To the best of our knowledge, this is the first study performing a pre-operative radiographic measurement on the affected hip. The second aim was to evaluate whether there are a minimum CEA and ADWR values that can predict a hemiarthroplasty instability. We hypothesized that the patients who have small CEA and/or ADWR have an increased risk of hip dislocation, despite the use of the ABMS approach, and might be addressed by a THA to reduce the risk of dislocation.

MATERIALS AND METHODS

We retrospectively analyzed 867 patients from our database of patients who underwent hemiarthroplasty for femoral neck fracture at a single orthopaedic hospital between January 1, 2014 and January 1, 2019. We included patients who were diagnosed with a displaced femoral neck fracture, classified as grade IV according to Garden classification [19], who underwent surgery through the ABMS approach, with a minimum of 6 months of follow-up, and were aged above 70

years. Patients younger than 70 years were excluded since, according to our institute's guidelines, they are treated with a THA or internal fixation for believed to be better functional outcomes. It is worth mentioning that some oncological cases or in polytraumatized patients in coma who have a low life expectancy were occasionally treated with hemiarthroplasty rather than a THA because of their comorbidities. The necessity to have the femoral head in its native position, for radiographic measurements led us to consider only the Garden IV fractures since the Weitbrecht's retinaculum is interrupted and the proximal femoral fragment is free, the trabeculae on radiography appear normally aligned, and the femoral head preserves its native center of rotation. The exclusion criteria were different surgical approaches other than the ABMS, less than 6 months of follow-up, non-Garden IV fractures, and patients previously operated in different Institutes (n=487). According to the inclusion and exclusion criteria, we analyzed 380 patients out of 867 who underwent bipolar hemiarthroplasty for femoral neck fracture through the ABMS approach. There were 282 women and 98 men. The demographic and radiological data of both groups are summarized in Tables 1 to 2. The mean time between the initial surgical operation and the dislocation was 1.5±1.1 months (range, 0.1 and 8.3). The mean follow-up was 36 months (range, 12 to 54). A total of 18 patients (4.7%) sustained a hip dislocation during the study period, and the remaining 362 patients who had no dislocation were used as a control group.

The surgeries were performed by five experienced hip surgeons. The ABMS approach was adopted, and a bipolar hemiarthroplasty was implanted. The types of stems used were the followings: Profemur Gladiator (Microport, Shangai, China); H-Max (Lima, San Daniele del Friuli, Italy); Polar Stem (Smith & Nephew, Memphis, USA); Exacta (Permedica Merate, Italy); and Amistem (Medacta, Castel San Pietro, Switzerland). The decision to cement the femoral stem was made by consideration of the bone quality and the surgeon preference. There were 267 (70.3%) femoral stems cemented and 113 (29.7%) press-fit. Patients were positioned supine on a standard table which allowed us to perform intra-operative X-Ray imaging. Both legs were draped sterilely into the operative field. A 7 to 10 centimeter oblique incision was made between the antero-superior iliac spine (ASIS) and the tip of the greater trochanter (GT). The incision was deepened to the level of the deep fascia and the iliotibial tract was longitudinally incised and retracted in the antero-posterior direction. The muscular plane between the gluteus medius muscle laterally and the tensor fascia latae muscle medially was bluntly developed by finger dissection and maintained with retractors. The fat pad in the anterior portion of the joint capsule was dissected, the rectus femoris identified and elevated, and then the capsulotomy was performed. After the bipolar hemiarthroplasty prosthesis was implanted, the closure of the fascia allowed restoration of the intermuscular space without any muscular damage or detachment [20].

The bipolar head size was decided according to the native femoral head dimensions in order to restore the anatomy of the hip. We measured the femoral head size intra-operatively with a caliber and we chose the same size as the native femoral head or, when in doubt between 2 dimensions, we chose the smaller size. Routinely during the procedure, a single antero-

posterior (AP) pelvis radiograph was taken with the trial femoral broach, femoral head and femoral neck in place to evaluate femoral alignment, femoral sizing, leg length, and offset. All patients underwent the same rehabilitation protocol, followed by a professional physiotherapist. Patients were allowed full weight bearing, using crutches from the first postoperative week, according to the general health status. Patients were evaluated with pelvis and hip (AP) and lateral views) radiographs at 1 and 3 months postoperatively and then followed up for a minimum period of 6 months. Patients who suffered a hip dislocation within the follow-up period were compared to the cohort of patients who did not have a dislocation. Demographic data, baseline characteristics, medical comorbidities, and the following patient-related risk factors were analyzed: age, sex, body mass index (BMI), American Society of Anesthesiology (ASA) Score, diabetes mellitus (DM), Heart disease (myocardial infarction, congestive heart failure), postoperative lower extremity deep vein thrombosis (DVT), neuromuscular diseases (such as cerebral infarction, Parkinson's disease), and dementia.

Radiological Measures

Pre-operative analyses of the AP fractured hip radiographs were performed to evaluate two morphological parameters: the Central-Edge Angle (CEA) as described by Wiberg [21] (Figure 1) and the Acetabular Depth-to-Width Ratio (ADWR) as described by Heyman and Herndon [22] (Figure 2). The CEA was defined as the angle between the vertical axis of the pelvis and a line passing to the center point of the femoral head and perpendicular to the inter-teardrop line. The vertical axis of the pelvis was represented by a line connecting the centers of the femoral heads bilaterally. The center of the femoral head was assessed through the center of a best-fitting circle outlining the femoral head (Figure 1). For this reason, we only included the fractures classified as grade IV according to Garden, as previously explained. The ADWR was defined as the ratio between the acetabular depth and acetabular width, multiplicated by 100. The acetabular width was measured from the lateral acetabular rim to the most inferior aspect of the teardrop, while the acetabular depth was the perpendicular distance from the line of the acetabular width in its halfway to the deepest acetabular portion (Figure 2). On the post-operative radiographs of the pelvis, calibrated on the cephalic head of the prosthesis, the leg length discrepancy (LLD) and the femoral offset (FO) of both the affected and healthy side were measured and compared between the dislocation and control group (Figures 3 a to c). LLD was measured as the difference in perpendicular distance between the top of the lesser trochanter to the line passing through the lower edge of the teardrops. The offset distance was obtained by measuring the distance between the longitudinal axis of the femur to the center of the femoral head [12]. The affected and healthy sides' FO were matched to obtain a delta and a mean delta FO and compared between the dislocation and the control groups. The measurements were performed by two independent blinded orthopaedic surgeons on two occasions using the TraumaCad version 2.0 system (BrainLab, Feldkirchen, Germany). In addition, after

surgery, we collected the data of the biarticular head dimensions on the surgical reports and we compared the data between the two groups.

Data analyses

The Shapiro-Wilk tests were used to assess for the normality of the distribution of continuous variables. Descriptive statistics (means, standard deviations, ranges, and medians as appropriate) were used to describe the patients' variables and radiological data. Categorical variables were assessed using *chi*-square or Fisher's exact tests for statistical significance. Continuous variables were compared using an unpaired *t*-tests as appropriate. Receiver Operating Characteristic (ROC) curves were performed and then studied analyzing the optimal cut-off for CEA and lower ADWR. *P*-values <0.05 were considered statistically significant. The intraclass correlation coefficients (ICC) were used to quantify the inter- and intra-rater reliability of all radiographic measurements. ICC values greater than 0.90 indicated excellent reliability. Statistical analyses were performed using Statistical Package for Social Science (SPSS) statistics software version 25.0 for MACINTOSH (IBM, Armonk, New York).

RESULTS

Eighteen patients (4.7%) sustained a hip dislocation during the study period, 14 (77.8%) were anterior and 4 (22.2%) were posterior. Comparing these 18 patients to the 362 who did not have a hip dislocation, the statistical analysis did not reveal significant differences in terms of sex (*p=0.173*), BMI >30 (*p=0.362*), DM (*p=0.505*), postoperative lower extremity DVT (*p=0.177*), heart disease (*p= 0.443*) and ASA score median 3 (range, 2 to4), and median 2 (range, 2 to 4) in the dislocation and control group respectively (*p=0.101*). Furthermore, patients who had neurological comorbidities such as dementia (*p=0.967*) and neuromuscular diseases (*p=0.382*) did not show a higher rate of dislocation. The analysis of the type of implant did not reveal any significant correlation between the cementation of the implant and the hip instability (*p=0.732*). Furthermore, the sub-analyses of stem types did not show any significant difference between the 2 groups (*p=0.564*).

Radiological outcomes

On the preoperative radiographic measurements, the 18 patients who had a hip dislocation had significantly smaller mean CEA (*p=0.0001*) and lower mean ADWR (*p=0.001*) than the control group. In detail, the patients who had a hip dislocation had a mean of 36.1±7.5° and 34±6° of CEA and ADWR, respectively. The control group had significantly higher mean CEA and ADWR, respectively 43.2±5.6° and 37±4°. A ROC curve analysis (Table 3, Figures 4 a and b) showed statistically significant cut-offs of 38.5° for the CEA (*p= 0.0001*) and 34.5 ADWR (*p=0.017*). In absolute number, this means that 7 out of the 285 patients (2.5%) who had a CEA higher than 38.5° had a hip dislocation while 11 of the

95 patients (11.6%) who had a CEA less than 38.5° developed a hip dislocation (*p=0.0003*). The same was found for ADWR: 8 out of 284 patients (2.8%) who had an ADWR more than 0.345 had a hip dislocation, while 10 of 96 patients (11.4%) who had an ADWR less than 0.345 develop a hip dislocation (*p=0.002*). Furthermore, 50% of the patients who sustained a hip dislocation (9/18) had a combination of both risk factors (CEA <38.5° and an ADWR <34.5). In absolute number, 9 out of 37 patients (24.3%) who had both risk factors had a dislocation, while 9 out of 343 patients (2.6%) who had one or no one risk factor suffered of hip dislocations (*p<0.001*).

On postoperative radiological examinations (Table 2), the LLD between the affected side and the healthy side in the dislocation group and the control group (1.2±3.5 and 1.2±4.2 millimeters, respectively) did not reveal any statistically significant difference (*p=0.478*), as well as no statistically significant difference between the two groups was found in delta femoral offset (*p=0.227*). The delta offset between the affected side and healthy side in the dislocation group was 1.5±4 and in the control group was 0.6±4. The postoperative analysis of the biarticular femoral head size between the dislocation group and control group did not reveal any significant difference (*p= 0.355*), with a mean size of 46.3±2.1 and 46.7±3.5 millimeters, respectively.

DISCUSSION

Hip dislocation following a hemiarthroplasty for a femoral neck fracture is a relatively uncommon, but devastating complication, especially for frail patients [11,23]. To the best of our knowledge, some studies report several risk factors for hip dislocation following a hemiarthroplasty [10,11,13-20], but there are no published studies examining the pre-operative acetabular morphology to predict instability following bipolar hemiarthroplasty. In our analysis 18 out of 380 patients (4.7%) had a postoperative hip dislocation. Either a smaller pre-operative CEA or lower ADWR or a combination of both morphological factors were significantly associated with instability.

Many authors already described an increased risk of dislocation related to the postero-lateral approach, ranging from 5.6 up to 16% [19, 21-24]. We used the ABMS approach on all patients and we registered a dislocation rate of 4.7%, lower than the rate reported using the postero-lateral approach. In addition, our dislocation rate is concordant with the data reported for hemiarthroplasty through either an antero-lateral or direct lateral approach, ranging between 3 to 6% [17,25]. Even though our cohort dislocation rate falls within the rate described in the scientific literature, it is still relatively high for an ABMS approach, especially if compared to a recent multicentric analysis that reported higher stability of the implant following a hemiarthroplasty (2.4%) rather than a THA [27]. This could be attributed to the higher median age of our group (approximately 90 years) when compared to the group described by the above-mentioned study (79 years). Furthermore, the high rate of anterior dislocation we reported, 14 out of 18, might be justified by age-related muscle

weakness and the laxity of the anterior capsule that we do not routinely repair during surgery, which is, however, not comparable with the large randomized controlled HEALTH trial [27] where the authors do report neither surgical approach nor the direction of the dislocation.

In our analysis, no significant correlation was found between hip dislocation and baseline/medical characteristics such as age, sex, BMI, ASA score, diabetes mellitus, heart disease, neuromuscular diseases, and dementia. According to our results, the medical risk factors reported in the scientific literature were mostly inconsistent showing non-significant results of increased risk of dislocation [12,24–26]. Few authors report a significantly higher risk of dislocation in women and a delay in surgery >24 hours as significant risk factors of hip dislocation [23,28]. Other authors suggested that the difficulty to maintain patients who have impaired cognitive function in a suitable posture postoperatively might increase the risk of dislocation during the early postoperative period [24,29]. Furthermore, an increased risk of postoperative dislocation within 90 days of surgery is reported in patients affected by neuromuscular diseases, especially Parkinson's disorder [30,31]. Neurologic impairments affecting the hip position in the resting state and muscle unbalancing due to paresis, spasticity, or tremors may be responsible for the increased risk of dislocation. Alternatively, our data conflict with the literature regarding the significantly increased risk of instability related to dementia and neuromuscular disorders. The conflicting results might be related to the fact that the majority of authors who reported the dislocation rate after bipolar hemiarthroplasty in patients who have neurological disorders, performed a postero-lateral surgical approach [12,26,30]. In this regard, we feel confident to say that the preservation of the strong posterior hip structures, using an ABMS approach, might be a protective factor against posterior dislocation in patients affected by a neuromuscular disorder.

In our cohort study focusing on preoperative radiological parameters, patients who sustained a hip dislocation had a significantly smaller preoperative CEA and lower ADWR than the control group. A ROC curve analysis showed that patients who had a CEA of $\leq 38.5°$ or an ADWR ≤ 34.5 were significantly more likely to suffer dislocation after bipolar hemiarthroplasty despite they were not considered to have acetabular dysplasia [32,33]. Morphological risk factors were widely analyzed by many authors, but mainly focused on the postoperative radiographs [1,19,24,31]. However, in agreement with our results, many authors reported that patients who have smaller CEA and ADWR, on post-operative radiographs, were more prone to hip dislocation after hemiarthroplasty for a femoral neck fracture. Madant et al [26] analyzing a cohort of 575 patients who underwent hemiarthroplasty through a postero-lateral approach, and reported smaller CEA angles in patients who had a dislocation (42 vs. 47°, $p=0.029$). Mukka et al [12] and Ninh et al [13], using the postero-lateral approach with the reconstruction of the short external rotators and joint capsule, found that a low CEA (40 vs. 46° in Mukka's cohort and mean CEA of 30.4 ± 5.3 in Ninh et al) was related to an inherent instability of the hip.

Zhang et al [1] reported that patients who had a CEA smaller than 45.4° were significantly more prone to suffer dislocation after bipolar hemiarthroplasty than the control group. Furthermore, many authors reported statistically significant lower ADWR or acetabular depth in patients who have hip dislocation [1,19,24]. On the other hand, we did not find significant differences with regard to post-operative radiological factors that may be controlled by the surgeon. Indeed, we do not report a statistically significant difference in mean LLD and delta FO between the dislocation and the control group. These data conflict with what authors previously reported about the discrepancy of offset and the LLD being factors significantly associated with hip dislocation [12,24,26]. This discrepancy might be associated with the use of the ABMS approach excluding the postero-lateral approach related to the risk of instability [17,34]. The absence of a significant correlation between dislocation and post-operative LLD and delta FO reinforces the importance of the preoperative measurements of CEA and ADWR as significant dislocation risk factors following hemiarthroplasty. These factors may, to a certain extent, be controlled by the surgeon. Indeed, based on pre-operative radiological CEA and ADWR, surgeons could choose to implant a THA that has the advantage of correcting the acetabular morphology, even if the ABMS approach is performed.

The present study has several limitations. It is a non-randomized and retrospective analysis of a relatively small cohort of patients. Also, the incidence of dislocation was 4.7% (18 patients), because of this relatively small group, the study findings may fall short of statistical significance. Furthermore, to perform the measurements on preoperative radiographs we could include only femoral neck fracture Garden grade IV. Strengths of our study is the homogenous group of patients, and the novelty of the study to perform the risk factor measurements in preoperative radiographs, differently from the current literature.

CONCLUSION

In conclusion, excluding the dislocation risk factor related to the surgical approach, we advise measuring the CEA and ADWR on pre-operative radiographs. In cases of either a CEA smaller than 38.5° or an ADWR smaller than 34.5 or a combination of both, changing the native acetabular morphology implanting a THA might help reduce the risk of dislocation and prevent further operations in an elderly and frail patient. However, when addressing elderly patients who have multiple comorbidities and a short life expectancy, even when they possess pre-operative morphological risk factors for a hemiarthroplasty dislocation, the decision to perform a THA instead of a hemiarthroplasty needs to be a multidisciplinary decision.

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Figure 1 Central-Edge Angle (CEA) is the angle measured between two lines from the center of the femoral head, line A is perpendicular to the bi-ischiatic line and line B passes through the lateral acetabular rim. The circle was drawn to underline the acetabular floor.

Figure 2 Acetabular Depth-to-Width Ratio (ADWR) is the ratio between acetabular depth and acetabular width multiplicated by 100. The acetabular width is made from the lateral acetabular rim to the most inferior aspect of acetabular teardrop (line C). Acetabular depth (line D) is the perpendicular distance from the line C in its halfway to the deepest acetabular portion. The circle was drawn to underline the acetabular floor.

Figure 3. a) Leg Length Discrepancy (LLD) is the difference of the length of the lower limbs measured as the difference in perpendicular distance between the top of the lesser trochanter to the line passing through the lower edge of the teardrop points. b) Healty-side Femoral Offset (FO) is the offset distance between the longitudinal axis of the femur to the center of the femoral head on the non-operated hip. c) Affected FO is the offset distance between the longitudinal axis of the femur to the center of the femoral head on the operated hip

Figure 4. Receiver Operating Characteristic (ROC) Curves analysis a) Central-Edge Angle b) Acetabular Depth-to-Width

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Table 1. Comparison of baseline data, medical data, preoperative acetabular measurements and post-operative measurements between dislocation and control group.

Baseline/Medical Data	*Total*	*Dislocation Group*	*Control Group*	*P Value*
Patients (n)	380	18 (4.7%)	362 (95.3%)	
Sex Men Women	 96 284	 2 16	 94 268	*p=0.173*
Mean age in years (range)	90 (73-105)	90 (73-100)	90 (75-105)	*p=0.196*
BMI cohorts >30 <30	 9 371	 1 17	 8 354	*p=0.362*
DM	64	2	62	*p= 0.505*
Heart Disease	60	4	56	*p=0.443*
ASA score	median 2 (range 2-4)	median 3 (range 2-4)	median 2 (range 2-4)	*p=0.101*
Postoperative DVT	31	3	28	*p=0.177*
Dementia	125	6	119	*p=0.967*
Neuromuscular Disease	31	0	31	*p=0.382*
Cemented Femoral Stem	267	12	255	*p=0.732*

BMI: Body Mass Index, DM: Diabetes Mellitus, ASA: American Society of Anesthesiology, DVT: Deep Vein Thrombosis. P-values <0.05 were considered statistically significant.

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Table 2. Comparison of preoperative acetabular measurements, post-operative measurements and biarticular femoral head size between dislocation and control group.

Morphological Factors	***Dislocation Group***	***Control Group***	***P Value***
Pre-operative X-rays			
CEA° (angle)	36.1 ± 7.5°	43.2 ± 5.6°	*p= 0.0001*
ADWR	34 ± 6	37 ± 4	*p= 0.001*
Post-operative X-rays			
LLD (mm)	1.2 ± 3.5	1.2 ± 4.2	*p= 0.478*
Delta Offset (mm)	1.5 ± 4	0.6 ± 4	*p= 0.227*
Biarticular Femoral Head Size (mm)	46.3 ± 2.1	46.7 ± 3.5	*p= 0.355*

CEA: Center-edge Angle, ADWR: Acetabular Depth to Width ratio, LLD: Leg Length Discrepancy. P-values <0.05 were considered statistically significant.

Table 3: CEA and ADWR of the patients as criterion for dislocation

Test Result Variable (s)	***Cut off value***	***Sen.%***	***Spec. %***	***AUC***	***95% CI AUC***		***P***
					Lower Bound	***Upper Bound***	
Center-edge Angle	**38.5°**	76.8	61.1	0.769	0.653	0.884	*0.0001*
Acetabular Depth to Width Ratio	**34.5**	76.2	65.4	0.667	0.508	0.826	*0.017*

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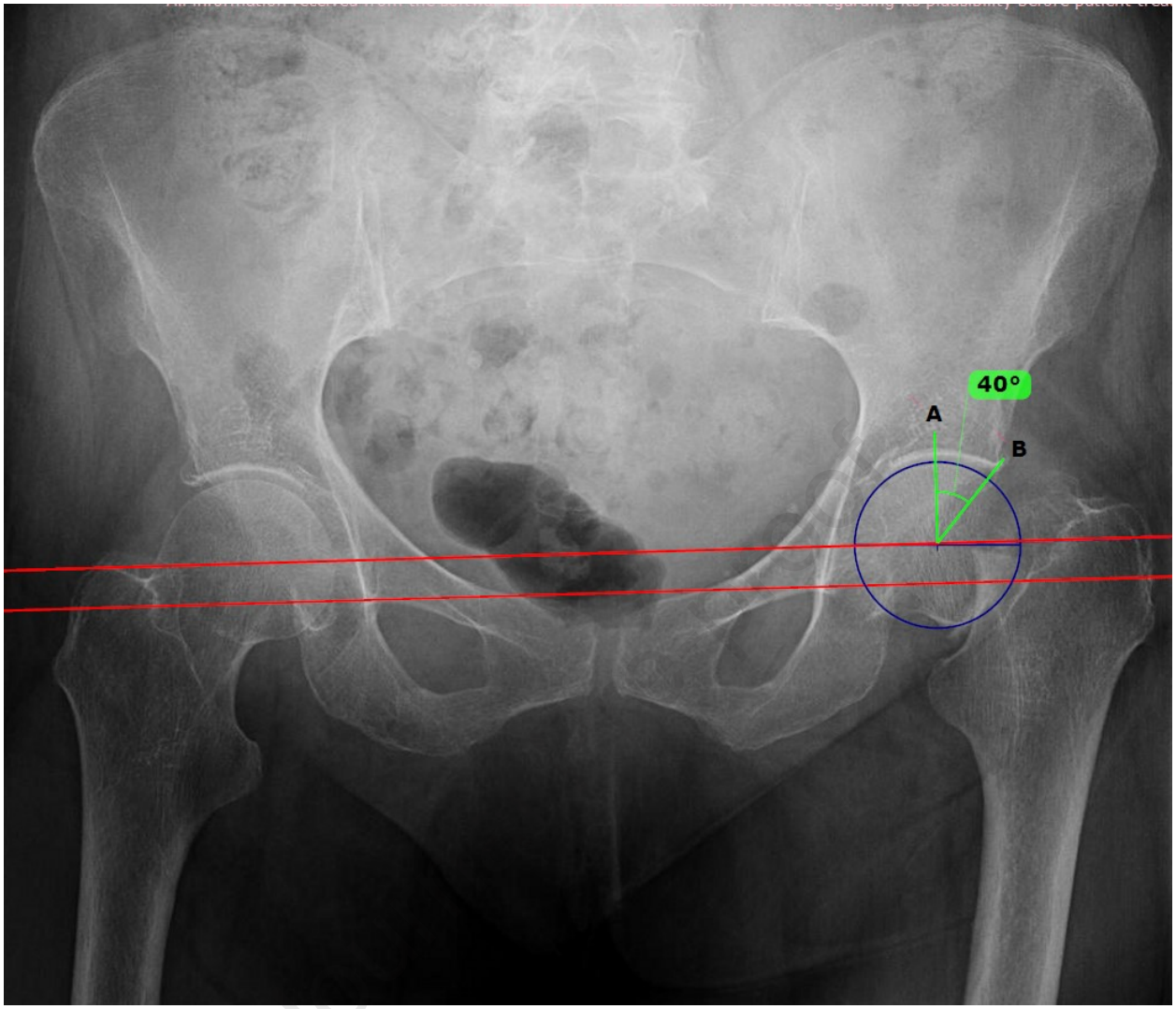
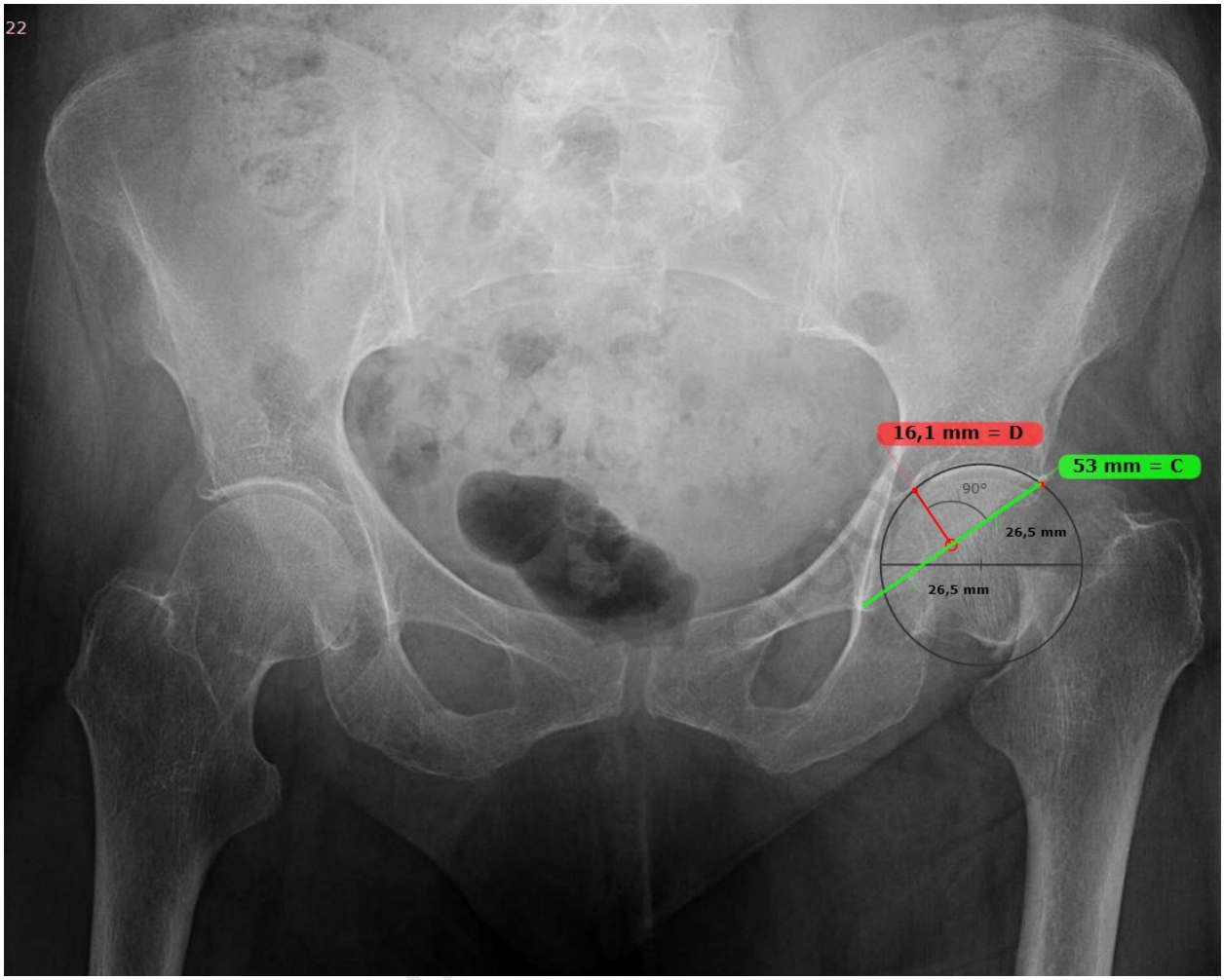

40°
A
B



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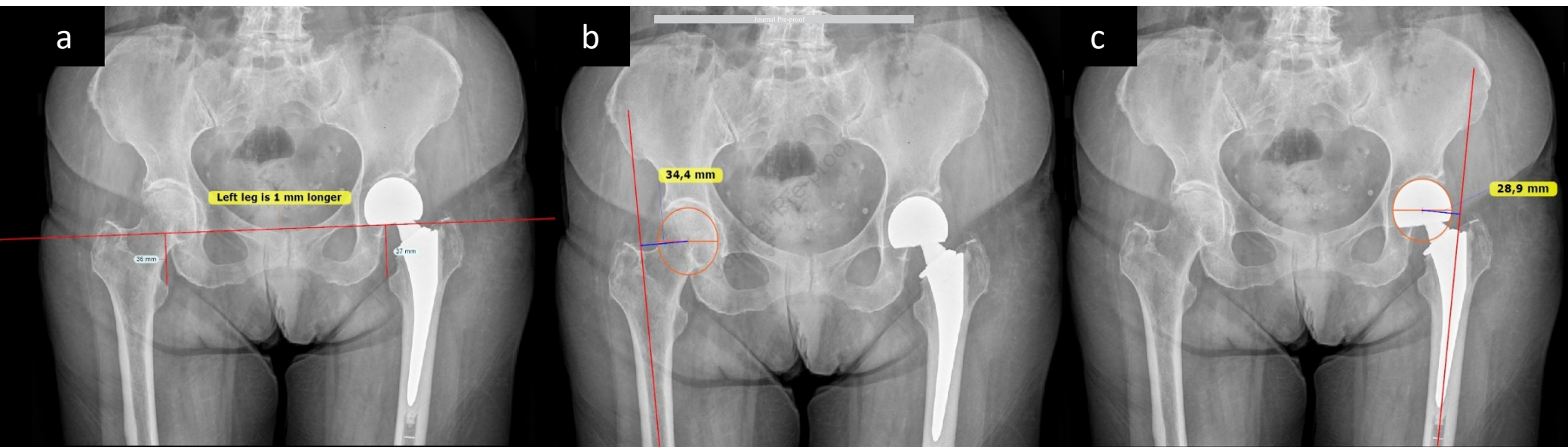
a
Left leg is 1 mm longer
36 mm
37 mm
b
34,4 mm
c
28,9 mm

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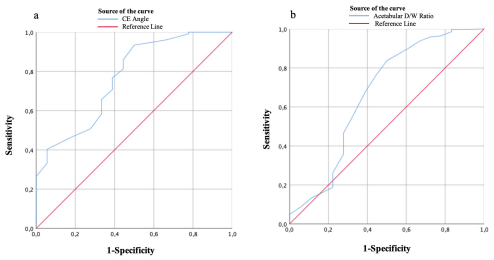

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