

Femoral and Global Femoral Offset, but not Anteroposterior Offset, to Improve Postoperative Outcomes Following Total Hip Arthroplasty: Considerations Independent of the Contralateral Side

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The global femoral offset (the sum of the acetabular and femoral offsets) influences outcomes after total hip arthroplasty (THA). The optimal offset using plain radiographs has been reported, but internal and external rotations of the hip affect the offset value, producing unclear results when the nonsurgical side is not intact. We investigated the relationship between a functional hip score, *i.e.*, the Harris Hip Score (HHS) and its effect on the post-THA anteroposterior and lateral offsets, and we sought to identify the optimal offset value. The cases of 158 patients with hemilateral hip osteoarthritis who underwent THA at a single center were retrospectively analyzed in this cross-sectional study. Three-dimensional pelvic and femoral models generated from computed tomography were used to examine several parameters, and the results revealed a significant binomial correlation among the modified HHS and femoral and global femoral offsets, with maximum values of 21.3 mm and 40 mm/100 cm body height, respectively. Pelvic and femoral parameters were measured and evaluated via alignment with a specific coordinate system. Our findings indicate that preoperative planning using these parameters may improve postoperative hip function, even when the nonoperative side is unsuitable for use as a reference, as in bilateral hip osteoarthritis cases.

Key words: total hip arthroplasty, global femoral offset, postoperative outcome, three-dimensional analysis, anteroposterior offset

A total hip arthroplasty (THA) relieves pain and improves hip function and daily living activity in patients with hip osteoarthritis (HOA). However, inadequate outcomes including residual pain sometimes occur, and attempts to improve the postoperative hip function of individuals who have undergone a THA are ongoing. The global femoral offset (GFO), which is the sum of the acetabular offset (AO) and the femoral offset (FO), is related to post-THA outcomes and functioning

including pain, hip function, and weakness of the muscles around the hip joint [1-11]. Many studies have used plain radiographs to evaluate the internal or external rotation of the hip in the assessment of the FO [1-4, 6-13], and only a few studies have used a three-dimensional method [5, 14]. As Hirano *et al.* noted, it is difficult to assess GFOs obtained using two-dimensional methods for direct application to preoperative planning, particularly in cases involving stem anteversion [5]. Moreover, anteroposterior offsets such as the anterior

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femoral offset (AFO) defined by Yoshitani *et al.* [15] can be assessed only with lateral radiographs (and not plain anteroposterior radiographs); the use of a unified coordinate system is thus necessary [5]. In addition, the above-cited reports were based on a comparison of the patients' contralateral side with the surgical side and included statements such as a recommendation that the GFO be <5 mm from the intact side [1]. If the reference side is also affected by HOA or osteonecrosis of the femoral head, the optimum post-THA offset thus remains unclear.

In this study, we investigated the relationships among the GFO, the anterior pelvic offset (APO; the distance from the pubic symphysis to the center of the femoral head), the AFO, the global pelvic offset (sum of the AFO and APO), and the Harris Hip Score (HHS) after THA. We also sought to identify the optimal offset values to improve post-THA functioning and outcomes, independent of the contralateral side, based on an analysis of the cases of 158 patients with hemilateral hip osteoarthritis who underwent THA at our institution.

Patients and Methods

Patients. Patients who underwent a THA at our institution (Niigata University Medical and Dental Hospital, Niigata, Japan) between January 1, 2010 and January 31, 2021 were included. Their cases were included if all of the following inclusion criteria were met: the patient (*i*) had hemilateral hip osteoarthritis (HOA) that did not involve the contralateral side; (*ii*) had a central end angle $\geq 25^\circ$ on the nonoperated side; and (*iii*) were asymptomatic. The exclusion criteria were the following: patients who had (1) a history of any surgery at the lumbar spine or lower extremity such as the knee; (2) knee osteoarthritis evaluated as $\geq$ grade in the Kellgren–Lawrence classification; (3) severe subluxation in the hip evaluated as Crowe type 3 or 4 on plain radiography; or (4) missing data. We also excluded patients with bilateral HOA because the pain and/or hip function of the nonsurgical side may have affected the function of the surgical side during the study period.

Surgical procedure. All of the THAs were performed by one of seven trained orthopedists using the anterolateral approach with the patient in a supine position [16–18]. The orthopedists aimed to place the acetabular cup close to the original hip center, at 40° of the radiographic inclination and 15° of the radiographic

anteversion, using the functional pelvic plane as a reference. This represents the tilt of the sagittal plane of the anterior pelvic plane, which contains the top of the pubic symphysis and the bilateral superior iliac spine in the supine position [19]. When the bony coverage of the acetabulum was low, we planned to obtain sufficient bony coverage, such as a cup center edge (CE) angle $\geq 0^\circ$. Therefore, no target value for AO was established during preoperative planning in this study period. The femoral component was planned $15\text{--}25^\circ$ in anteversion, with reference to the retrocondylar plane (RCP) [20] (*i.e.*, the plane containing the most posterior points of the greater trochanter and bilateral femoral condyles) such that, when summed, the combined anteversion was approx. $30\text{--}40^\circ$ [21,22].

The anteversion angle of the femoral component was planned according to the original anteversion. However, we intentionally increased or decreased this angle by $15\text{--}25^\circ$ depending on the anteversion. Cemented stems were used in cases that required an increase or decrease in the anteversion by $> 15^\circ$. The FO was also planned so that the GFO would be approximately equal to that of the healthy side, including anteversion and the implant selection such as the offset of the stem itself.

All of the acetabular components in this patient series were uncemented implants. Regarding the femoral component, mainly uncemented implants were inserted (Table 1).

Table 1 Demographic data of the participants

Sex (male/female)	37/121
Age (years)*	56.4 $\pm$ 10.3 (34–78)
Surgical side (right/left)	93/65
Primary disease	DDH: 128 Osteonecrosis of the femoral head: 28 Primary HOA: 3
Tönnis grade†	0: 0 1: 0 2: 19 3: 139
Dorr's classification†	A: 2 B: 146 C: 10
Femoral component	Uncemented: 149 Cemented: 9

* Mean $\pm$ standard deviation (range).

† Evaluated by plain anteroposterior radiograph of the hip joint before THA

DDH, developmental dysplasia of the hip; HOA, hemilateral hip osteoarthritis.

Ethical considerations. The study protocol was approved by the Niigata University Ethics Review Committee (approval no. 2019-0051), and the tenets of the Declaration of Helsinki were followed. We used an opt-out method, and the requirement for patients' written informed consent was waived because this was a cross-sectional retrospective study with no patient interventions.

Measurement. A three-dimensional (3D) digital model of the bone was created using ZedView[®] software ver. 16.0.0 (Lexi Co., Tokyo) [23] from computed tomography (CT) images that had been obtained in order to conduct preoperative 3D planning and evaluate the implant placement 1 week postoperatively [24, 25]. A 64-row detector equipped with a multi-slice CT scanner was used to obtain approx. 600 slices (1.25 mm slice thickness) at each limb (Aquilion 64 TM; Toshiba Medical Systems, Tochigi, Japan).

As illustrated in Fig. 1, we first adjusted the pelvic 3D model to the anterior pelvic plane with the use of ZedView[®], and we examined the AO (*i.e.*, the distance

from the most distal point of the teardrop to the center of the femoral head). A 3D model of the femur was aligned with the RCP, and the anterior pelvic plane and RCP were adjusted in parallel (Fig. 2) [26]. As depicted in Figure 3, we then measured the FO (the distance between the axis of the proximal femur and the femoral head center), the AFO, and the GFO [27] when the X, Y, and Z coordinates were in parallel (see Fig. 2). The APO was defined as the distance between the pubic symphysis and the femoral head center in the pelvic Y-axis (Fig. 4). The global pelvic offset (GPO) was defined as the sum of the AFO and APO (Fig. 4).

The APO and GPO were assessed when the X, Y, and Z coordinates were adjusted in parallel (Fig. 4). The AO, FO, GFO, AFO, APO, and GPO in this survey were thus considered to have uniform values that were unaffected by the hip position, such as flexion, abduction, and rotation. We corrected all of the measurement values per 100 cm of the patient's body height for a body size adjustment in order to make it easier to calculate the length such as AO, FO, GFO, to adjust to the height of each patient during the actual planning. The insertion angle of the acetabular component was assessed by radiographic definition [19], with reference to the pelvic coordinate system's functional pelvic plane. The stem anteversion angle was assessed as the angle between the posterior condyle tangent to the RCP and the stem axis.

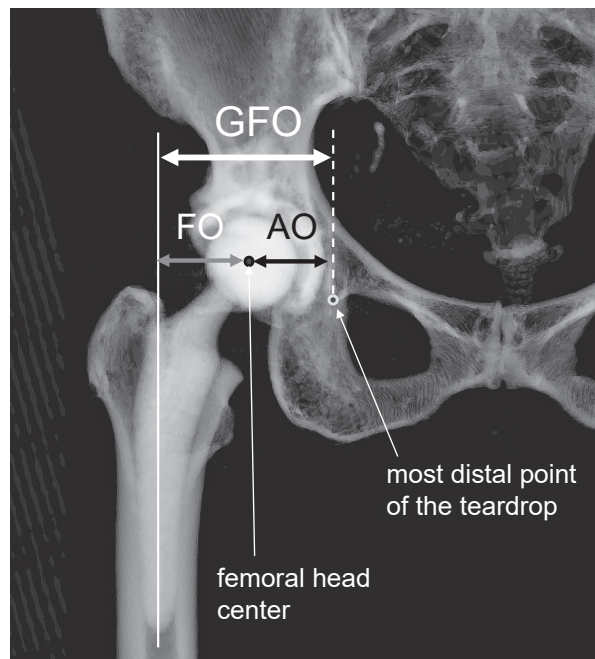


Fig. 1 Measurement of the acetabular and femoral offsets. **A**, The acetabular offset (AO) is the distance between the center of the femoral head and the teardrop measured in the pelvic coordinate system; **B**, The femoral offset (FO) is the distance between the center of the femoral head and the axis of the proximal femur measured in the femoral coordinate system.

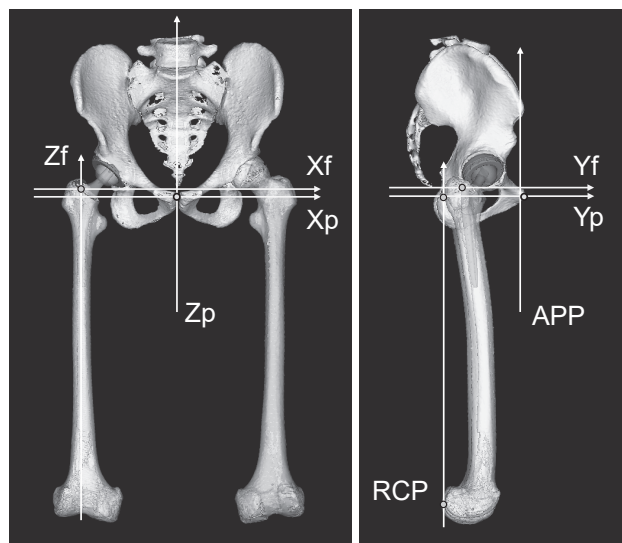


Fig. 2 The X, Y, and Z coordinates of the pelvis and femur were adjusted so that the coordinates are in parallel.

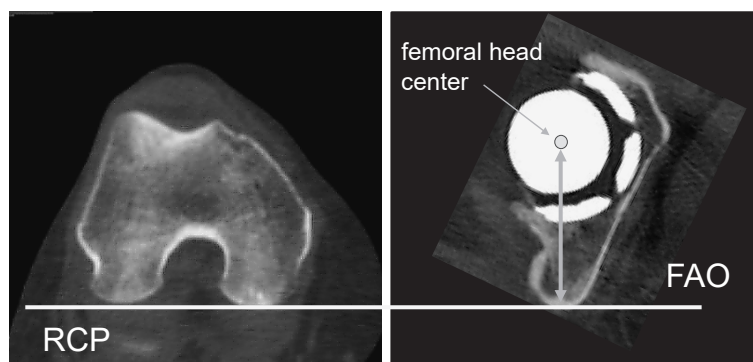


Fig. 3 Measurement of the anterior femoral offset (AFO), *i.e.*, the anteroposterior distance between the center of the femoral head and the retrocondylar plane (RCP) in the axial plane of the femoral coordinate system.

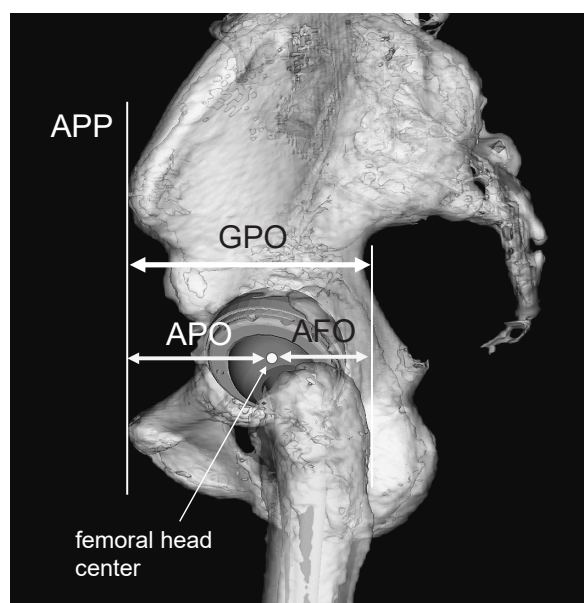


Fig. 4 The definition of the global pelvic offset (GPO): the sum of the anterior femoral offset (AFO) and the anterior pelvic offset (APO).

Each patient's HHS value was obtained by an experienced orthopedic surgeon within 2 months before the THA and 1 year after the THA. The modified Harris Hip Score (mHHS) was later used to place more emphasis on function and activity [28]. All of these data were obtained from the patients' medical records and analyzed herein.

Statistical analysis. We performed a linear regression analysis using the operative side's AO, FO, AFO, APO, GFO, and GPO measurements and the 1-year postoperative mHHS total score, since a too large or too small AO, FO, AFO, APO, GFO, and

GPO may be not suitable for the 1-year postoperative mHHS total score [1, 5], which were also evaluated with a binomial approximation. If a significant association was observed, the maximum value was determined as described [5].

We defined the mHHS cutoff value >80 as a good outcome [29]. This value was calculated by using the maximum value of the binomial approximation as the center, and the absolute values around them were calculated with the use of a receiver operating characteristic (ROC) curve to determine the acceptable range. For the identification of correlations, we performed a post hoc analysis for statistical power (type II [β] error) with 0.5 as an effect size (d) and 0.05 as the type I (α) error. Intra- and interobserver reliabilities were evaluated using the intraclass correlation coefficient (ICC). Intraobserver reliability was measured at least twice with a ≥ 2 -week interval. Statistical significance was set at $p < 0.05$. SPSS statistical software ver. 28 (SPSS, Chicago, IL, USA) was used to analyze the data.

Results

The cases of a total of 158 consecutive patients (121 females, 37 males) were included and all participants completed the survey without dropping out. Table 1 summarizes the patients' demographic data. The acetabular cup was placed $40.0 \pm 4.9^\circ$ (mean $\pm$ SD) at inclination and $16.8 \pm 6.1^\circ$ at anteversion, respectively, and the stem was placed $26.3 \pm 10.9^\circ$ at anteversion. The patients' total mHHS scores increased significantly from 49.0 at 2 months before the THA to 88.8 at 1 year after the THA.

The measured values of the pelvic and femoral

parameters following the THAs are shown in Table 2. Significant correlations were observed between FO and GFO values and the mHHS values binomially, with the maximum values of 21.3 mm/100 cm body height and

Table 2 Measurement value of pelvic and femoral parameters after total hip arthroplasty

	Surgical side	Healthy side
AO (mm)*	18.7 ± 2.5 (11.–25.7)	18.7 ± 2.5 (11.–25.7)
FO (mm)*	22.0 ± 3.5 (12.5–32.3)	22.0 ± 3.5 (12.5–32.3)
GFO (mm)*	40.7 ± 4.8 (27.8–52.4)	40.7 ± 4.8 (27.8–52.4)
AFO (mm)*	23.0 ± 4.7 (10.5–36.7)	23.0 ± 4.7 (10.5–36.7)
APO (mm)*	33.4 ± 3.4 (24.4–45.2)	33.4 ± 3.4 (24.4–45.2)
GPO (mm)*	56.4 ± 6.0 (33.8–71.2)	56.4 ± 6.0 (33.8–71.2)

*Mean ± standard deviation (range). These values were adjusted to 100 cm of body height.

AO, acetabular offset; FO, femoral offset; GFO, global femoral offset; AFO, anterior femoral offset; APO, anterior pelvic offset; GPO, global pelvic offset.

40.0 mm/100 cm body height, respectively (Fig. 5B, C; Table 3). The mHHS ≥ 80 cutoff value based on the ROC curve was 2.0 mm. As depicted in Fig. 6, the area under the curve (AUC) for the FO was 0.628 ($p < 0.038$), and the following values were obtained: sensitivity 0.621, 1 – specificity 0.333, and 2.8 mm as the cutoff for the GFO, and AUC 0.610 ($p < 0.047$), sensitivity 0.586, 1 – specificity 0.275, and 2.0 mm as the cutoff for the FO. The power analyses using paired *t*-tests and correlations yielded power values of 0.941 and 0.980, respectively. The intra- and interobserver reliabilities ranged from 0.835 to 0.929 for all measures.

Table 3 Formulae calculated with regression equation

	Formula	Correlation coefficient
*	$y = -0.1331x^2 + 5.6719x + 30.275$	$r = 0.249$
**	$y = -0.0654x^2 + 5.2146x - 13.654$	$r = 0.292$

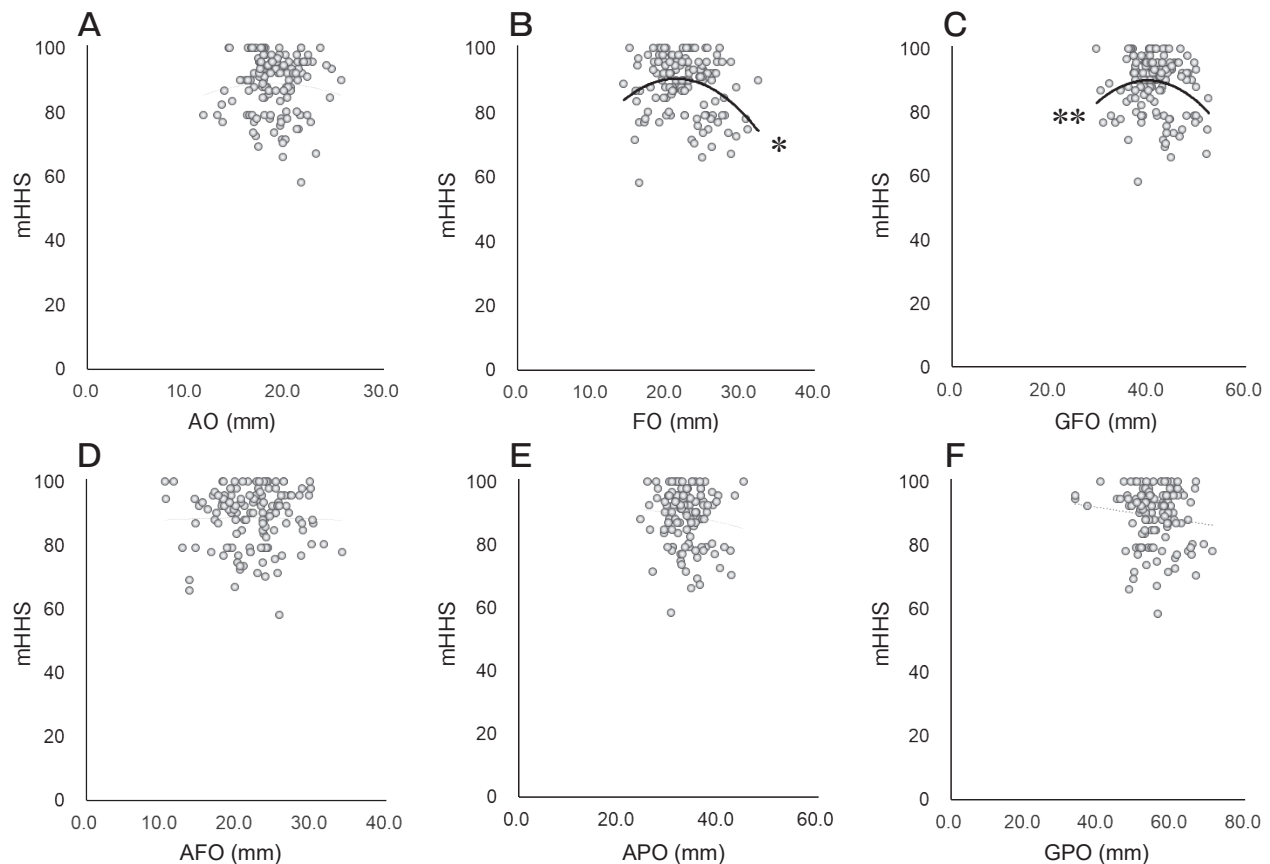


Fig. 5 Correlation of the patients' modified Harris Hip Score (HHS) values and pelvic and femoral parameters. The modified Harris Hip Score (mHHS) and femoral offset (FO) (B*) and the global femoral offset (GFO) (C**) were significantly correlated.

No adverse events affecting the postoperative course occurred during the study period such as dislocation, surgical site infection (with sepsis), or fracture. No obvious displacement or loosening of the implant was observed on plain radiographs between immediately after THA and 1 year post-THA. No medical complications that could have affected the postoperative course were observed.

Case presentations.

1. Patient 1

The patient was a 56-year-old Japanese female with HOA. Her postoperative FO and GFO value measured using the 3D method were 22.5 mm and 40.8 mm/100 cm body height, respectively; these values were considered suitable FO and GFO values (Fig. 7A, B). The preoperative mHHS value was 34 (pain, 11; function, 23)

and the postoperative mHHS was 100 (pain, 48; function, 52).

2. Patient 2

The patient was a 61-year-old Japanese male with osteonecrosis of the femoral head. The postoperative FO and GFO measured using the 3D method were 19.0 mm and 36.8 mm/100 cm body height, respectively. These values were considered low for the FO and GFO (Fig. 8A, B). The patient's respective pre- and postoperative mHHS values were 51 (pain, 22; function, 29) and 77 (pain, 44; function, 33).

3. Patient 3

This was a 66-year-old Japanese female with osteonecrosis of the femoral head. The postoperative FO and GFO measured using the 3D method were 24.0 mm and 44.5 mm/100 cm body height, respectively. These

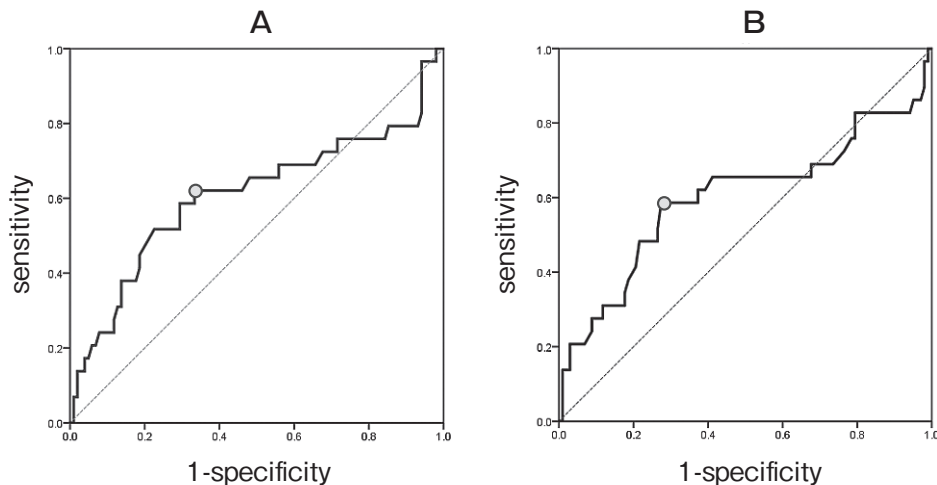


Fig. 6 The cutoff values of the femoral offset (FO) and global femoral offset (GFO). The cutoff value obtained for the FO (A) was 2.0 mm, and that for the GFO (B) was 2.8 mm.

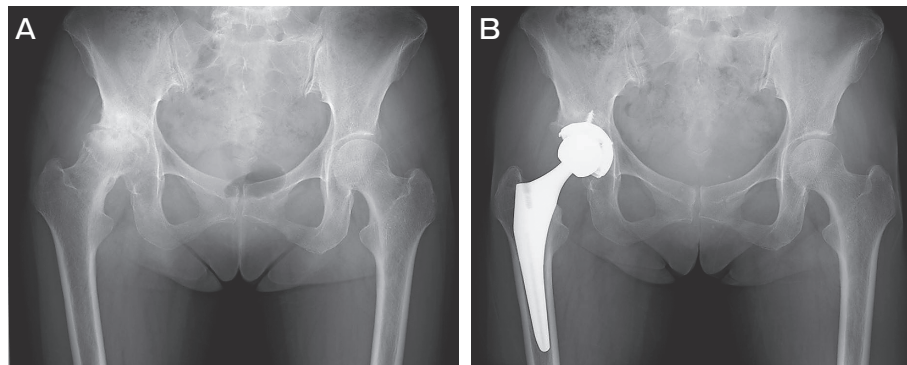


Fig. 7 Pre- (A) and postoperative (B) plain radiographs of Patient 1.

values were considered high for the FO and GFO (Fig. 9A, B), and the patient reported experiencing greater trochanter pain after his THA. The pre- and postoperative mHHS values were 48 (pain, 22; function, 24) and 74 (pain, 33; function, 41), respectively.

Discussion

Our present findings indicate that a suitable range for the FO is 19.3-23.3 mm/100 cm body height, and a suitable range for the GFO is 37.2-42.8 mm/100 cm body height. For a patient whose body height is 157 cm (which was the average height of this patient series), suitable values for the FO and GFO are thus 30.3-36.6 mm and 58.4-67.2 mm, respectively. Prior investigations have indicated that the optimal difference in GFO between the THA side and intact side is ~5-20 mm [1-11,30]. We speculate that if the FO and/or the GFO are shorter on the operative side than on the nonoperative, the patients' intact side—with reduced muscle

strength around the hip joint, especially the abductor muscles, and consequently less hip function such as walking distance and speed—will produce dull pain related to muscle fatigue around the hip joint and in the lower extremities [2,12]. However, lengthening of the FO and/or GFO can result in pain around the greater trochanter and iliotibial tract, which is called 'greater trochanteric pain syndrome' [10,13].

Andronic *et al.* concluded that 'snapping hip syndrome' was more likely to occur when the percentage of the FO reflected in the GFO is large, and the syndrome's main factor was an increased FO [10]. Moreover, an excessive increase in the FO can lead to ipsilateral knee pain, resulting in loss of hip function [31]. Overextension of the FO should therefore also be avoided. Restoring the GFO contributes to reduced postoperative pelvic obliquity [6], and thus restoring the GFO or aligning it with that of the patient's intact side is important. However, such findings are only useful if the contralateral side is used as the reference, and

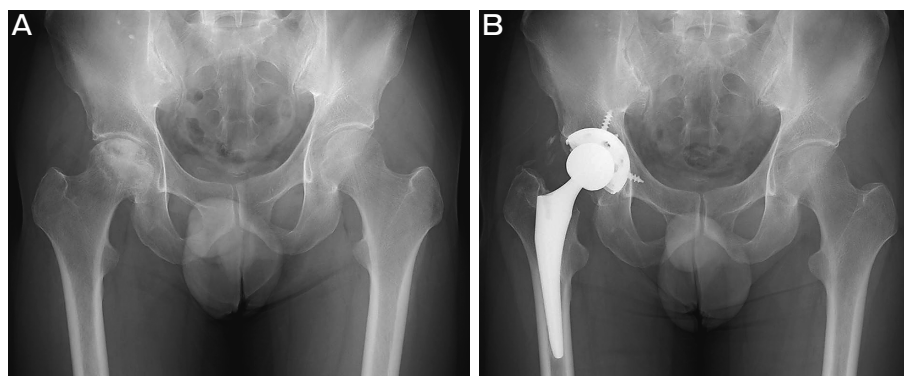


Fig. 8 Pre- (A) and postoperative (B) plain radiographs of Patient 2.

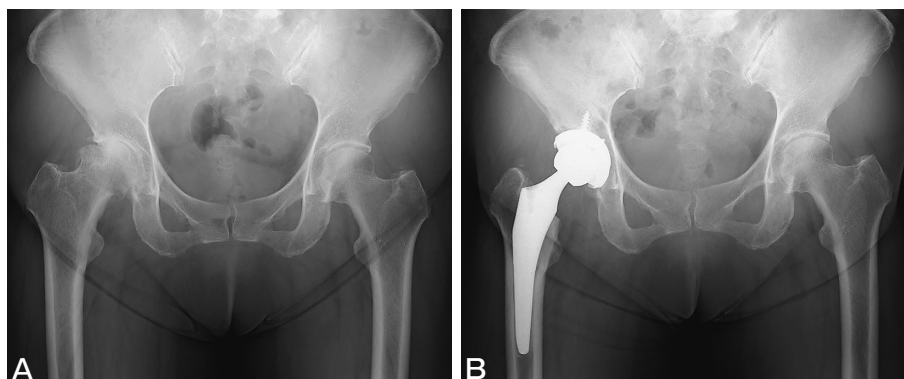


Fig. 9 Pre- (A) and postoperative (B) plain radiographs of Patient 3.

it is unclear whether this is the case when the contralateral side is not suitable as the reference, such as in patients with HOA or a dislocated hip. Moreover, our research group has demonstrated that the best postoperative outcomes following THA were obtained when the AO was 1-2 mm smaller and the GFO was 1-2 mm larger than those on the healthy side [6, 14]. In other words, while it is important to adjust the AO and GFO so that the values are close to those of the patient's healthy side, it is not always best for these values to be identical to the healthy side's corresponding values, and a target value that does not depend on the opposite side should thus be sought.

Lecerf *et al.* reported correlations between the FO and the endomedullary shape: the hip center tended to move in a medial direction in stovepipe metaphysis of the geometry of the proximal femur, whereas it tended to be lateralized for 'champagne flute' upper femurs [27]. Most of our present patients had Dorr type B bone, and when we determined the FO, we thus paid attention to the geometry of the medullary cavity as well. There are several important factors to consider in order to obtain a target FO value. First, the anteversion angle must be determined considering the combined anteversion, because this is related to the dislocation, impingement, and long-term survival of the implant. Second, an implant with a stem geometry and an offset to obtain the target FO should be selected; in some cases, the model also needs to be considered. The use of cemented stems may need to be considered in cases of poor fitting with the bone geometry of the femur. The head length could also be used to achieve an appropriate GFO and to account for a leg-length discrepancy, if necessary. Surgeons should consider these factors to achieve better postoperative outcomes.

Our findings revealed that a suitable range of FO and GFO values existed without a comparison with the intact side. To the best of our knowledge, this study provides the first report in which measurements did not rely on reference to the intact side, and our results are thus applicable to cases in which the nonoperated side is unsuitable for use as a reference, such as in bilateral HOA cases.

Conversely, our analysis results demonstrated that the AO, AFO, APO, and GPO were not associated with the total mHHS value, possibly because the range of the AO was not as large as those of the other parameters. However, several research groups have recom-

mended that the AO should be slightly smaller than that on the intact side [5, 9]. Hirano *et al.* reported that the lowest mHHS pain scores were obtained when the AO was reduced by approx. 2 mm compared to the intact side [5]. Ollivier *et al.* reported that a reduction in AO was beneficial to reduce the load on the prosthesis [9]. However, they also stated that the resulting reduced GFO should be compensated for and adjusted by increasing the FO in order to achieve long-term stability [9]. Therefore, the acetabular component should be placed slightly medially. We observed that the AO, AFO, APO, and GPO did not affect the present patients' postoperative outcomes as much as the FO and GFO did in the absence of severe deviation. When surgeons perform a THA, securing the FO and GFO should thus be prioritized over anterior-posterior offsets such as the AFO, APO, and GPO. The present study is the first report of this noteworthy observation. A unique feature of this study is that both the pelvis and femur were evaluated by aligning them to a specific coordinate system.

Our review of the relevant literature identified only a few studies that used a 3D method. When evaluated with plain radiographs, neither the FO nor the GFO can be accurately assessed, due to differences in hip rotation [5, 32]. Using plain radiographs in preoperative planning as a direct reflection of the values obtained from the survey [1-4, 6-13] is therefore unsuitable, especially regarding stem anteversion, which also affects the FO and GFO. We considered and evaluated these factors, obtained from plain radiographs herein, and the results are of high clinical value. With the exception of the study by Hirano *et al.* [5], other studies have not considered differences in patient body size such as height [1-4, 5-11, 30]. This is also a strong point of our analyses.

This study has some limitations to address. The sample size was relatively small ($n = 158$ hips). This was a single-center, retrospective, cross-sectional study, which may limit the applicability of our findings to other patient populations. The assessment method used was the mHHS, and the results showed that functional scores were associated with all parameters studied; however, different findings may be obtained with the use of other evaluation tools such as patient reported outcome measures (*e.g.*, the Health Survey Short Form-36 and the Japanese Orthopaedic Association Hip Disease Evaluation Questionnaire) that cannot be fully expressed

using the mHHS; further research is thus necessary. In addition, evaluations using clinical scores instead of the mHHS may reveal the range of suitable GFOs.

Our study did not consider leg-length discrepancy, which is considered one of the dependent factors that affect hip function and outcome [5,13]. In a recent report, leg-length discrepancy was not considered as an independent influencing factor following THA [32]. It thus seems that considering differences in leg length would not have had a significant impact on the results we obtained in this study. Moreover, since the parameters examined in this study are associated with poor performance when they are too small or too large, it is challenging to calculate the contribution of each parameter using conventional methods such as multivariate analysis. We thus applied the method described herein to obtain the results. A final study limitation is that we evaluated the implantation angle only once after the patients' THAs, although no obvious implant displacement or loosening was observed on plain radiographs between the timepoints immediately after the THAs and 1 year after the THAs. Evaluations of implant displacement or loosening were not part of this study because, if an accurate evaluation were to be completed, an examination by CT would be required. Despite these limitations, this is the first study to measure the parameters using a 3D method and to determine an optimal offset that is independent of the opposite side.

In conclusion, for patients who underwent a THA, the clinical results were the most favorable when the parameters such as the FO and GFO were measured by aligning and evaluating both the pelvis and femur in a specific coordinate system. The femoral and global femoral offsets 21.3 mm and 40 mm/100 cm body height, respectively were identified as optimal values. Preoperative planning for a THA that applies the present findings may lead to improved postoperative outcomes, even when the nonoperative side is not suitable as a reference.

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