ORIGINAL ARTICLE

Total hip arthroplasty offset measurement: Is C T scan the most accurate option?

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Summary

Background: Femoral offset is difficult to precisely evaluate with conventional X-ray techniques. Femoral offset characterizes the balance between body weight and the resistance provided by the abductor muscles. Total hip arthroplasties should respect this balance.

Hypothesis: Computed tomodensitometry (CT-scan) is more accurate than conventional X-ray to evaluate femoral offset.

Materials and methods: Sixty-one patients who received unilateral total hip arthroplasties were prospectively included in the study. Femoral offset was measured by three-dimensional CT-scan reconstruction using the ''Hip Plan'' (Symbios™) software. Offset was also determined with conventional X-ray and results were compared. This software can be used to measure leg length by frontal telemetry. It was developed for preoperative-planning of cementless femoral stem implants with modular necks of various lengths and angles. All pre- and postoperative measurements were made according to the same protocol.

Results: Femoral offset values in this study were very similar to anatomical values found in the literature. They were significantly higher than values obtained by conventional X-ray by an average of 8%. Implantation of hip replacements resulted in a significant increase in offset (1.88 ± 4.71 mm) with a slight variation in leg length. Pre- and postoperative leg length increased slightly in the operated leg by an average of 1.66 ± 5.63 mm. Seventeen percent of these femurs had high offset associated with small or average sized proximal medullary canals. This preoperative planning software made it possible to identify these difficulties and to adapt implant components using modular long 8° varus necks to restore high offset. In most

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of these cases, only small femoral stems could be implanted because of the small size of the intramedullary femoral canal. These individual differences were identified with 3D CT-scan reconstruction and included in the preoperative planning. Moreover, leg length could also be evaluated with this method and included in the preplanning.

Discussion: Compared to conventional X-ray, measurements obtained with this preoperative planning method using 3D CT-scan reconstruction are easy to obtain and not dependent upon test conditions because the frame is placed on the femoral axis. Measurements are not influenced by position inconsistencies or if the hip is fixed in external rotation. The significant number of cases with above average offset confirms the importance of obtaining these measurements and the necessity of adapting the strategy in these cases by using lateralized stems, or, as in our series, modular necks to adjust femoral offset and neck angle.

Level of evidence: Level III diagnostic prospective study.

Introduction

Femoral offset is a variable defined to describe the balance between the weight of the body and the resistance provided by the abductor muscles of the hip. Offset is the perpendicular distance from the center of hip rotation and the line of action of the abductor muscles [1]. Because this distance cannot be observed in daily clinical practice, a fixed radiographic value is used, which defines femoral offset as the perpendicular distance between the femoral metaphyseal axis (or the center line of the femoral canal) and the center of rotation of the femoral head [1].

Calculating femoral offset with frontal plane radiographic studies is limited by the precision of the radiographic technique, which is dependent upon many variables: 1) first, the patient's position, the position of the X-ray tube the distance between the tube and the plate, which determines the enlargement coefficient; 2) the image must be obtained along the femoral axis while an osteoarthritic neck is often fixed in external rotation. With computed tomodensitometry (CT-scan) other planes of reference can be visualised such as the axial plane, which can be used to measure anteversion according to Suh et al. [2] and Olivecrona et al. [3]. With computer assisted 3D CT-scan reconstruction, measurements can be obtained by maximizing the view of the femoral cervical axis [4].

For Charles et al. [5] offset calculated by frontal plane radiograph is an individual constant, which must be integrated into preoperative planning, and failure to restore offset may oblige the surgeon to lengthen the operated leg to sufficiently restore soft tissue tension and prevent postoperative implant instability. Finally, it is difficult to compare pre- and postoperative results with this technique because of imprecise reproduction.

For Charles et al. the choice of component size and component implantation affects functional results and Total Hip Arthroplasty (THA) longevity [5]. Preoperative planning should give the surgeon the opportunity to choose these components and restore leg length.

With 3D CT-scan reconstruction, the spatial characteristics of the patient's anatomy can be evaluated on one hand, and angles [2,3] or lengths can be measured [6,7] on the other, because the characteristics of the CT-scan workspace are well defined. Certain characteristics useful for surgery (measurement of angles, or evaluation of distances) can be obtained with implant simulation programs thanks to the standardized DICOM format. Computer assisted planning was found to be effective for simulations for Noble et al. [7] and virtual planning for Seel et al. [8]. Sari Ali et al. [4] have shown that these tools are effective for evaluating operated and contralateral leg length with frontal telemetry, and can effectively be used to choose the center of hip rotation, confirm articular range of motion and identify impingement.

We used a program of this type called ''Hip Plan'' (Symbios™) to calculate and compare variations in pre- and postoperative femoral offset in 61 patients who underwent THA. These measurements were included in our preoperative planning for implantation of a modular neck-shaft femoral stem, making it possible to adapt to variations in femoral offset as well as to plan for the neck-shaft component separately from the metaphyseal femoral stem and the acetabular components.

The purpose of obtaining preoperative femoral offset was to be able to plan for and choose a combination of hip replacement components that would restore this offset. We also associated leg length measurement into the preoperative planning protocol.

The main aim of this study was to compare conventional radiograph and CT-scan measurements of femoral offset. The second aim was the compare the pre- and postoperative values of femoral offset as well as the variations created by THA placement using the same protocol of analysis in a group of patients operated on by the same surgeon by the posterolateral approach.

Materials and methods

Patients

Sixty-one patients with unilateral arthropathies were included in this prospective study between September 2004 and March 2007. There were 45 women and 16 men, an average of 74 years old (44—83); the body mass index (BMI) was an average of 30.5 (22—45), 32 patients had a BMI above 30. The most frequent etiology was primary osteoarthritis in 55 patients, in four cases the etiology was osteoarthritis secondary to moderate dysplasia, in one case osteoarthritis secondary to end stage osteonecrosis, and in another case sequellae from a fractured pelvis, which had not been operated on with acetabular protrusion. The same surgical technique with a posterolateral approach was used by a single surgeon (GP) and all hip arthroplasties were primary.

All patients underwent pre- and postoperative CT-scans. Patients who refused scans were not included in this evaluative prospective study.

Methods

Collection of CT-scan data
The CT-scan examination was performed with a multi-row detector spiral device Siemens[TM], with the patient in the supine position with the legs fully extended and the knees straight. CT-scan included contiguous 2 mm slices of the pelvis between the iliac crests and the femoral isthmus, which corresponds to the narrowest section of the femoral diaphysis as well as frontal and profile telemetric images of the legs.

Description of ''Hip Plan[TM]'' software
Image processing and reconstructions were performed with the ''Hip Plan'' (Symbios[TM]) software, which was developed for 3D preoperative planning. ''Hip Plan'' is a software package to process and analyse 3D images. It is based on a software package that was initially developed to conceive and plan custom total hip replacements in cases of significant femoral dysplasia by Flecher et al. [9,10]. Three windows with coronal, sagittal and axial views, which are perpendicular at one point are seen simultaneously, providing 3D images. Thus, a reference point is naturally obtained where each slice defines one of the three planes. Navigation in this three dimensional space is obtained by moving this point (called the 3D cursor). The user can zoom in or reorient the 3D image in relation to this point (translation and rotation) [4]. This type of navigation makes it possible to compensate for poor positioning of the patient during image acquisition by making it possible to locate and mark the patient's anatomical references.

Two planes were systematically acquired: first the anterior pelvic plane as defined by the anterosuperior iliac spines and the anterior pubic tubercles, which is a plane that provides patient characteristics, and the craniopodal plane as suggested by Murray [11], which is a reference plane similar to a frontal plane radiograph.

Pre- and postoperative results could be compared and the affects of implantation could be analysed because anatomical references were precisely determined with this method.

Calculating femoral offset
To measure femoral offset, the upper quarter of the axis of the femoral medullary canal must be identified because the femoral curve is spatially complex [12,13]. This axis is placed in the center of the femoral metaphysis for the three planes of reference [4] (Fig. 1).

The coordinates of the center of the femoral head are then obtained by superimposing spheres of various sizes (millimetric variations) on the head, and the sphere, which corresponds most closely to the edges of the femoral head is taken as the diameter of the femoral head. The center is used to calculate offset. Femoral offset is the perpendicular distance between the center of the femoral head and the axis of the femoral metaphysis (femoral canal). The femoral offset may be calculated for the operated leg as well as the contralateral side, which was used as a control
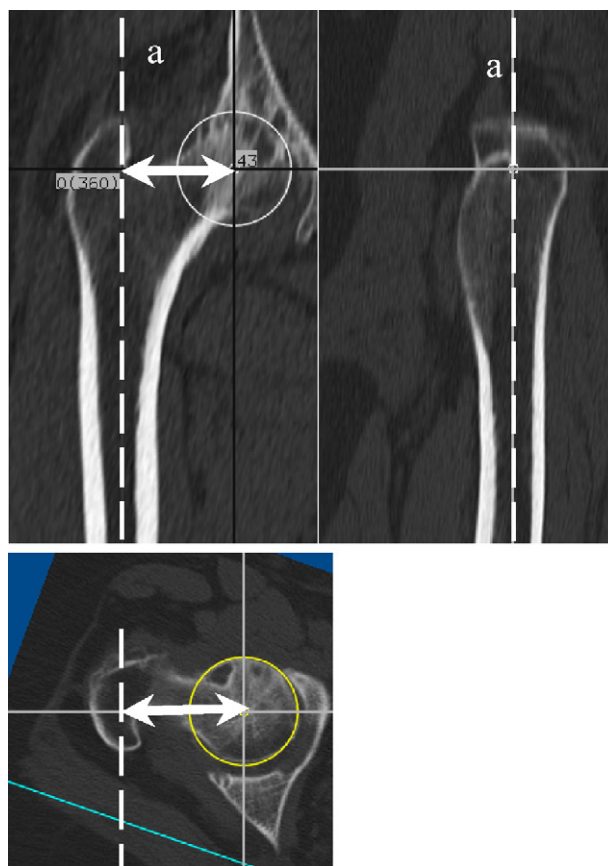

Figure 1 Determination of femoral offset with CT-scan data. The medullary femoral axis is determined (a), and the center of the femoral head is determined with different millimetre sized spherical templates. Offset is determined by the perpendicular line between the axis of the femoral canal and the center of the femoral head.
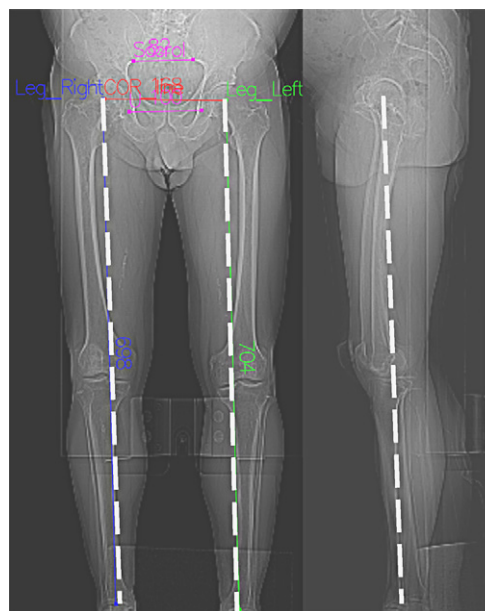

Figure 2 Evaluation of leg length. Value in millimetres, frontal view telemetry, profile telemetry confirms the absence of knee flexion.
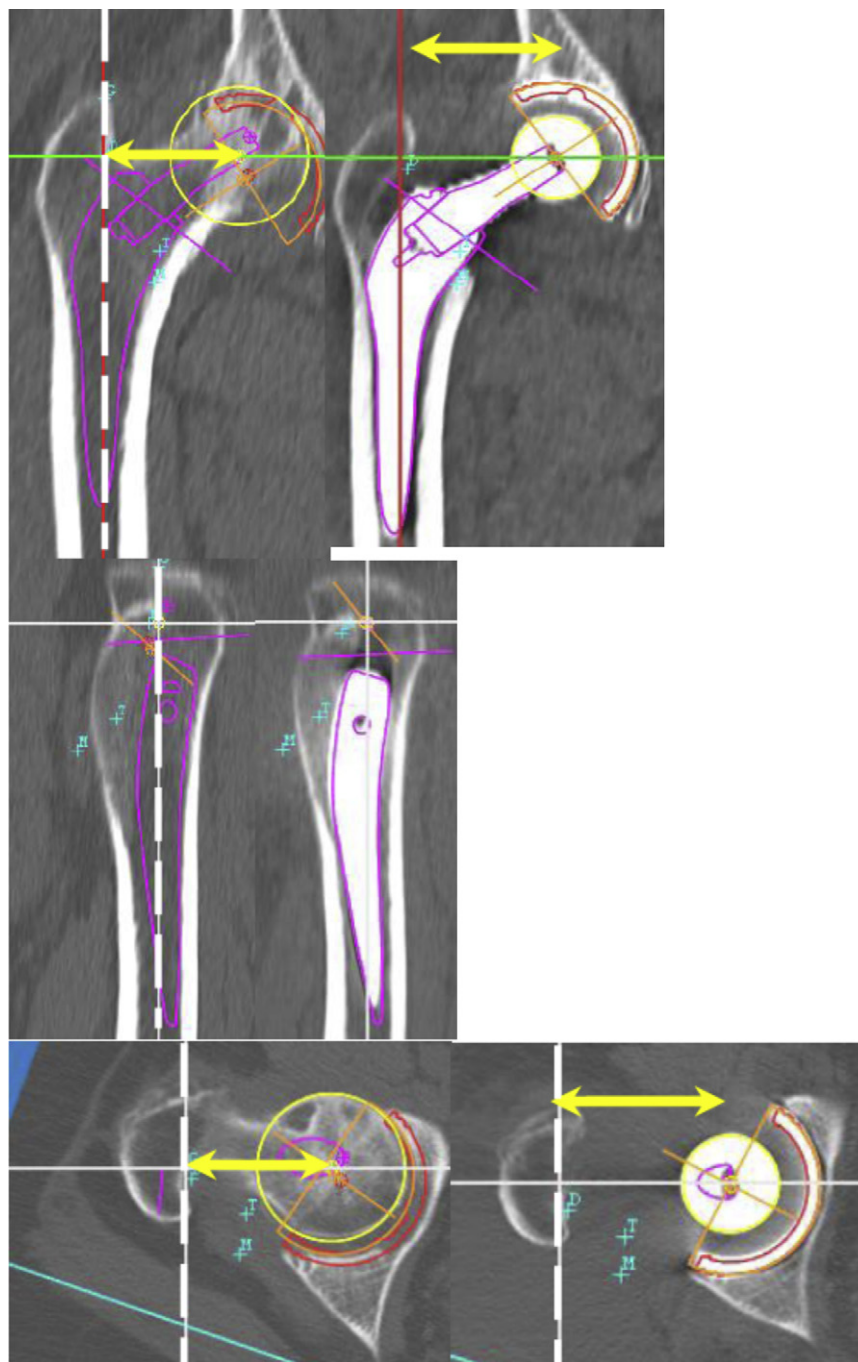
Figure 3 Pre- and postoperative use of software. Measurement of femoral offset in both cases, using different axial, sagittal and coronal planes, which can be simultaneously visualised and reoriented.

measurement in this study. Conventional radiographic offset was calculated pre- and postoperatively on X-rays of the pelvis, with the legs in full extension, knees straight.

Evaluation of leg length
Leg length was systematically evaluated with frontal plane telemetry in this protocol (Fig. 2). Profile telemetry confirmed the absence of any significant knee or hip flexion, which might falsify measurements. The distance between the center of the femoral head and the center of the tibiotalar joint was used to calculate leg length. The con-

trolateral side was systematically measured. Postoperative data was acquired in the same way during a follow-up CT-scan performed before patients were released and with their consent.

Hip replacements used
The Symbios™ cementless total hip replacement was used in all cases. There were two types of cementless anatomical femoral implants: either a monobloc stem (SPS) (with seven increasing sizes from B to H) or a modular anatomical stem with modular necks of various sizes (SPS modular) (six

increasing sizes from C to H). In the latter case, several neck shaft angles and lengths were available. The angle could be straight or inclined in 8° varus—valgus or with 8° ante- or retroversion in relation to the femoral neck axis. Two neck lengths were available for each angle and there was a difference of 9 mm between the ''short'' and the ''long'' neck. These modular neck were then fitted with classic modular head components with four possible sizes (−3 mm, 0 mm, +3 mm, +6 mm). The modularity of these various components provided a differential of 15 mm, in addition to various choices of lengths at the ''head-neck'' junction, providing numerous possible variations for restoring offset. Compared to the lack of precision of conventional X-ray, and considering the many theoretical possibilities with these components, computer-assisted surgical pre-planning, which is the primary purpose of ''Hip Plan'' software, made it possible to select the size of the femoral stem or acetabular cup components, to simulate the different possible combinations of the modular neck during pre-planning and to choose the elements that were best adapted to the patient's anatomy (Fig. 3). The acetabular component was made of titanium with a rough convex surface covered with hydroxyapatit, with three blocked openings in case any screws were necessary on the supraequatorial part of the head.

Statistical method

Statistical analysis of results was performed with JMP5.1 software (SAS Institute™). Comparison of means was performed with the Student t test. A p-value of less than 0.05 was considered to be significant. Comparison of continuous values was performed with the Student t test. A p-value of less than 0.05 was considered to be significant.

Results

General characteristics

Sixteen monobloc SPS stems were implanted and 45 modular SPS stems. Two types of modular neck angle components were used with the 45 modular SPS stems: the ''straight'' neck and the ''8° varus'' neck. The ''varus'' neck was used in 36 cases, with two ''long varus'' necks and 12 ''short varus'' necks. Nine modular SPS stems with ''straight'' necks were implanted with five ''short'' necks and four ''long'' necks. Dislocation did not occur in any of the implants in the present series, but in one case a feeling of implant instability developed at 1 year of follow-up.

Results for variations of femoral offset

Mean preoperative femoral offset was 42.90 ± 5.43 mm (31—55). The mean offset was higher in men (45.18 ± 3.68 mm) than in women (42.02 ± 5.76 mm), although the highest offset value was found in a woman (Table 1). This difference in offset between men and women was significant with the Student t test ($p < 0.001$).

Mean offset increased postoperatively 44.68 ± 6.29 mm (28—57) and the mean increase was comparable in men (47.69 ± 4.33 mm) and women (43.59 ± 6.57 mm). This increase in postoperative offset compared to preoperative offset was statistically significant with the Student t test ($p < 0.001$).

Mean femoral offset in the controlateral leg was 43.35 ± 5.71 mm with hardly any change between the pre- and postoperative CT-scan results. This value was slightly higher than preoperative femoral offset in the operated hips, but was similar to the postoperative value in operated hips (Table 2).

Radiographic results of offset were lower, with a mean of 39.97 ± 5.65 mm (26—52) for the entire group. This value was 42.00 ± 5.49 mm (32—52) in men and 39.00 ± 5.52 mm (26—49) in women, which was also statistically significant with the Student t test ($p < 0.04$) (Table 1).

Mean postoperative radiographically measured offset increased to 41.83 ± 6.45 mm (28—54 mm) with a comparable increase in men and women. This pre- to postoperative increase in offset was significant $p < 0.0001$.

There was a significant difference between radiographic and CT-scan offset measurements with the paired Student t test $p < 0.0001$. Radiographic offset was an average of 3.28 ± 4.11 mm (0—12.5 mm), or 8% less than CT-scan offset.

''Long varus'' subgroup

The average postoperative increase in offset in the subgroup of patients who received a modular ''long varus'' neck was identical to that for the entire group (Table 2).

A significant difference was found in the preoperative offset when the groups with different necks are analysed: ''long varus'' necks, ''short varus'' necks, modular or standard straight necks. The greatest average preoperative femoral offset was found in the ''long varus'' neck group and it was significantly different from the other groups with the Student t test $p < 0.001$.

In the 25 patients who received modular long varus necks, 10 had small femoral stems (C), 13 had average stems (D and E) and only two had large stems (F and G). Therefore, there was a frequent association between small femoral canals and long and/or varus necks.

Subgroup of patients with significant femoral offset

Thirteen patients out of 61 had a femoral offset at least two standard deviations above average, or an offset of 47 mm or more for women (eight cases) and 49 mm or more for men (five cases). Nine of these 13 patients received a modular long varus neck, including three patients with a +6 head component. In three cases, the pre- and postoperative comparison showed that offset was not restored, in one case it was equivalent and in eight cases it was moderately increased. Among these 13 patients, the majority of stems inserted were small or medium sizes: 11 size C—D—E stems were implanted, two size F and two size G. In this group of patients with high offset, as in the previous group with long varus neck implants, a narrow intramedullary canal was frequently associated with a long femoral neck. Thus, a narrow medullary canal was frequently found in the presence of normal or high femoral offset. This characteristic was clearly identified with 3D reconstruction and the size of the pre-planned femoral stem component could be precisely defined.

Table 1 Variation in offset following hip replacement (mean ± standard deviation).

	Preoperative femoral offset (mm)	Number	Postoperative femoral offset (mm)	Mean difference (mm)
Series CT Scan measurement[b]	42.90 ± 5.43[a] (31—55)	61	44.68 ± 6.29[a] (28—57)	1.88 ± 4.71
Women[c]	42.02 ± 5.76 (31—55)	44	43.59 ± 6.57 (28—54)	1.57 ± 4.99
Men[c]	45.18 ± 3.68 (37—51)	17	47.69 ± 4.33 (39—57)	2.75 ± 3.86
Contralateral hip	43.35 ± 5.71 (32—56)	61	43.11 ± 5.96 (30—56)	0.15 ± 2
Series radiographic measurement[b]	38.97 ± 5.76 (26—48)	61	41.83 ± 6.45 (28—54)	3.02 ± 5.39

[a] Increase in postoperative offset was statistically significant with the paired Student t test ($p < 0.001$).
[b] Significant difference between radiographic and CT scan offset with the paired Student t test ($p < 0.001$).
[c] Significant difference in offset between men and women with the paired Student t test ($p < 0.04$).

Variations in leg length

Three cases were not studied because of unsuccessful telemetry (ankles out of the frame) or because of the presence of flexion, which disturbed the measurements. The mean preoperative difference between the length of the two legs was low: -1.03 ± 3.90 mm (-6, $+9$ mm). The leg to be operated on was shorter in 30 cases, longer in 23 cases and equivalent in eight cases (Table 3). Comparison of pre- and postoperative CT-scan leg lengths showed that the operated legs had increased by a mean of 1.66 ± 5.63 mm (-15, $+13$ mm). Postoperatively, 37 patients had an operated leg, which was longer than the contralateral leg, 18 operated legs remained shorter and six were equivalent. The mean difference in length between the two legs on postoperative CT-scan telemetry was 1.15 ± 4.08 mm (-15, $+11$ mm). Five patients still had a difference of at least 10 mm between the two legs, three due to lengthening, two from shortening.

CT-scan measurements of contralateral leg lengths remained stable, with a mean difference between the pre- and postoperative measurements of 0.52 ± 3.77 mm for a mean pre- and postoperative length of 753 mm (Table 3).

Discussion

Results of the comparative study between conventional radiograph and CT-scan

For Eggli et al. [14] preoperative planning of THA is possible by superimposing templates on frontal and profile X-rays. The use of projected views with a theoretical enlargement of between 15 and 20% is based on the theory that the enlargement coefficient is the same for the images of the femur and the acetabulum. For De Thomasson et al. [15] precise estimation of the size and position of implants is not possible with this method.

The importance of restoring femoral offset has been noted by several authors. For Mc Grory et al. [16], if offset is maintained abductor muscle strength and thus implant stability is increased, and it is also beneficial for articular range of motion for Asayama et al. [17]. Restoring abductor muscle strength reduces limping [16,17] and can limit the risk of postoperative lengthening of the operated leg [1,2]. Femoral offset is difficult to determine radiographically in dysplasic hip femurs, which often have torsion anomalies [18,19].

Table 2 Variations in femoral offset according to the type of neck component chosen (mean ± standard deviation).

	Preoperative femoral offset (mm)	Number	Postoperative femoral offset (mm)	Mean difference (mm)
Series	42.90 ± 5.43 (31—55)	61	44.68 ± 6.29 (28—57)	1.88 ± 4.71
Long varus neck[a]	45.54 mm ± 5.27 (32—55)	24	48.58 ± 3.86 (41—57)	3.04 ± 3.92
Short varus neck	42.27 mm ± 4.27 (34—49)	11	42.73 ± 4.84 (35—49)	0.45 ± 4.08
Straight neck[a]	40.63 mm ± 5.04 (31—51)	26	41.89 ± 6.65 (28—56)	1.26 ± 5.54

[a] Significant difference between the ''long varus neck'' and the ''straight neck'' groups with the paired Student t test ($p < 0.001$).

Table 3 Variations in operated leg length and measurement of contralateral leg (mean ± standard deviation).

	Preoperative length (mm)	Number	Postoperative length (mm)	Mean difference in length (mm)
Operated leg length				
Series	751 ± 48[a] (650—869)	58	753 ± 48[a] (655—870)	1.66 ± 5.63
Women	742 ± 44 (650—853)	43	744 ± 43 (655—852)	1.49 ± 5.67
Men	776 ± 53 (698—869)	15	779 ± 52 (704—869)	2.13 ± 5.69
Contralateral leg				
Series	752 ± 48[b] (656—868)	58	752 ± 48[b] (656—868)	0.45 ± 3.65
Women	743 ± 43 (656—849)	43	743 ± 43 (656—850)	0.01 ± 3.43
Men	779 ± 52 (704—868)	15	778 ± 52 (696—868)	1.73 ± 4.04

[a] Variations in operated leg length were not significant between the pre- and postoperative measurements.
[b] Variations in contralateral leg length were not significant between pre- and postoperative measurements.

Femoral offset varies depending on the patients and the authors and ranges from 20 to 63 mm [12,13,20] (Table 4). With the increase in understanding of offset, manufacturers now offer femoral implants that are adapted to this variable: so-called ''lateralized'' implants, implants with different neck angles, or modular femoral neck shafts with different neck lengths and angles.

Although the importance of respecting femoral offset to improve the results of total hip arthroplasties has been described by numerous authors, the conventional radiographic technique seems to be unreliable for measuring this variable, especially for preoperative planning, because the osteoarthritic hip is often fixed in external rotation [13,15]. Our study shows that conventional radiographic frontal plane technique underestimates femoral offset. The morphology of the proximal femur has been analysed by several authors in anatomical studies of cadaveric bones whose average values are found in Table 4.

In a series of 200 femurs by Massin et al. [20], average femoral offset was 41.0 ± 6.2 mm (20.5—59 mm). In a study of 200 femurs by Noble et al. [12], average femoral offset was 43.0 ± 6.8 mm (23.6—61 mm).

Rubin et al. [13] compared the results of radiographic and CT-scan measurements of 32 cadaveric femurs to anatomical measurements. This study showed that results of proximal femoral geometry were approximate with conventional radiograph (frontal and profile view), a variable that is essential for cementless femoral implants. This group found a mean difference of 2.4 ± 1.4 mm between radiographic and anatomical values. They concluded that these results made it impossible to correctly choose the size of the implant or to manufacture a custom-made implant. Average CT-scan results of 0.8 ± 0.7 mm were considered to be more precise than radiographic results.

In that study anatomical femoral offset was calculated based on the criteria of Noble et al. [12] resulting in a slightly higher average of 47 ± 7.2 mm (33.2—62.8).

Our results show that the original measurement technique used in our study based on CT-scan associated with digital images and specific software was precise. The pre- and postoperative values of femoral offset measured with this method were comparable to and provided results similar to anatomical studies in the literature [12,13,20].

With this method of 3D CT-scan reconstruction, images can be recentered along predefined planes and femoral offset can be precisely determined by placing the frame on the femoral metaphyseal axis and the femoral diaphyseal axis. We found a significant difference between radiographic and CT-scan methods. The former resulted in values, which were significantly lower by an average of 8%. In our opinion, this difference is due to a less precise orientation of the neck of the femur during radiography. Underestimation of offset can affect the stability of the hip replacement and frictional wear of implant surfaces.

Relationship offset — length of the lower limb

During THA implantation, restoring soft tissue balance is essential for hip stability. There are several choices if the surgeon feels that stability is insufficient: increase neck length or reduce the neck angle of the femoral component or both. Each of these possibilities simultaneously

Table 4 Anatomical offset values in the literature.

	Noble et al. [7]	Rubin et al. [13]	Massin et al. [20]
Mean (mm)	43 ± 6.8(23.6—61)	47 ± 7.2(33.2—62.8)	41 ± 6.2 (20.5—59)
Number of femurs	200	32	200

affects leg length and soft tissue tension, which affects offset. As Charles et al. [5] have emphasized, increasing neck length causes leg lengthening and increases femoral offset, while reducing neck-diaphyseal femur angle increases offset more than it increases leg length. To restore offset in a diseased hips from various causes, this variable must be evaluated preoperatively, and the length of the leg in relation to the contralateral leg must be determined. As Ranawat et al. [21] have suggested, offset can be evaluated during surgery before dislocation and cutting of the femoral neck. It can also be confirmed after implantation of the replacement components during evaluation of hip stability by different manoeuvres, as suggested by Jasty et al. [22].

Numerous authors consider lateralization with increased offset (at least 4 mm) to be the best method to restore soft tissue tension by moderately lengthening the operated limb [1,5,12,17]. Maloney and Keeney [23] feel that maintaining preoperative leg length in the operated limb or avoiding postoperative lengthening of the operated leg is an important factor and results are not improved by radiographic preoperative planning for Konyves and Banister [24]. The length of both legs should be determined preoperatively and confirmed during surgery [1,5,21,22,24]. Maloney and Keeney [23] emphasize the poor postoperative tolerance of postoperative leg lengthening and the importance of preoperatively identifying length inequalities. Although the leg to be operated on is usually shorter, the opposite also frequently occurs and this should be included in preoperative planning. Konyves and Banister [24] estimate that lengthening occurs in 20% of legs with osteoarthritic hips requiring surgery, and found that 60% of legs had lengthened after THA. With the type of preoperative planning used in our study, leg length can be systematically defined, making identification of individual differences and determination of the surgical strategy easier. Can shortening in the operated limb be corrected? If it is not present, reducing the neck-diaphyseal femur angle is preferable, while respecting offset.

Discussion of the results

There is significant individual variability and a wide range of femoral offset values: in our series offset ranged from simple to double, while the range was even greater in anatomical series (from 20 to more than 60 mm) (Table 4). In our series, there was a significant similarity between femoral offset in the diseased leg and the contralateral side. In case of destruction of the femoral head, the offset of the contralateral side can be used if this side seems intact. Nearly one out of five patients who underwent surgery in our series had an offset that was at least 6 mm above average, or two standard deviations. Our preoperative planning method made it possible to successfully treat and integrate this frequent situation (17% of our series).

Moreover, in this series, the femoral necks with a significant offset were rarely associated with large femurs or medullary canals. Our initial CT-scan evaluation frequently showed femurs with significant offset and narrow medullary canals. This can easily be underestimated with radiographic preplanning. Offset must be restored in these femurs with small medullary cavities using stems to obtain sufficient lat-

eralization, or using appropriate modular components, such as modular metaphyseal—epiphyseal implants (ESOP-HA).

The wide range of femoral offset values confirms the importance of femoral stems with variable offsets, in particular in small and average sized femoral replacements. Our results confirm those of Krishnan et al. [25] who found a lack of correlation between the size of the medullary canal and offset.

The three-dimensional preoperative-planning system, which we have developed [4], facilitates the use of femoral implants with modular necks by helping the surgeon choose the most well-adapted combination of implant components. As our series shows, implantation of THA using preoperative planning with CT-scan makes it possible to restore or slightly increase offset.

The second risk of not identifying femurs with significant offset is lengthening of the operated limb, which may be necessary to restore soft tissue tension and obtain sufficient stability. Our results confirm those of Maloney and Keeney [23] and Konyves and Bannister [24] showing that preoperative leg length discrepancies must be included in preoperative planning.

Although lengthening is possible in patients with a shorter preoperative leg, this is not always true, as our study of leg length shows, and clinical evaluation of this variable is not always easy. Leg length of the limb to be operated should be evaluated preoperatively, and our choice of frontal telemetry provided a fairly constant value in both legs, and in the two CT-scan evaluations, as shown by the limited variation between the measurements of the contralateral side in the two tests. Simultaneous profile telemetry confirmed the absence of knee flexion, which would falsify results. Knowledge of preoperative leg length limits the risk of postoperative lengthening by making it possible to choose a strategy, which is adapted to the patient:

(1) if the operated limb is longer or the same length in the preoperative evaluation, no lengthening is necessary, restoring offset is preferable;
(2) if the operated limb is shorter, length should be adjusted and offset restored.

If the limb to be operated is not shorter in the preoperative evaluation, offset should be restored and a smaller neck angle (''varus'' neck in our series) is preferable for good stability. Our series showed a moderate average increase in femoral offset after THA, even in the group of patients with high offset. This moderate increase in offset was associated with slight increases, and a low overall average lengthening of the operated leg, probably because this variable was managed in association with offset in our preoperative planning.

Conclusion

We propose a new technique for calculating femoral offset, which seems to be reliable compared to the anatomical data in the literature. Femoral offset is calculated with this technique using multislice CT-scan on a PC. Pre- and postoperative results can be compared if necessary. Hips with high offset can be identified. Knowledge of offset associated

with preoperative planning, facilitates the choice of the most well-adapted implant components to obtain sufficient femoral offset and obtain good hip stability. The possibility of evaluating the length of both legs is an additional aid in this type of planning, allowing more precise determination of the surgical strategy. This technique is well-adapted to the use of modular neck implants, providing a wide range of neck lengths and angles. This series shows the importance of these components, in particular a modular long ''varus'' neck, which makes it possible to restore high offset. We were surprised by the frequent association of a long neck and a narrow intramedullary canal, which confirms the lack of correlation between offset and metaphyseal—diaphyseal morphology.

Conflict of interest

E Durante: computer developper at Symbios (Yverdon).

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