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ORIGINAL ARTICLE

Accuracy of the preoperative planning for cementless total hip arthroplasty. A randomised comparison between three-dimensional computerised planning and conventional templating

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KEYWORDS
Total hip arthroplasty;
Positioning criteria;
Preoperative planning;
Navigation

Summary
Introduction: A high accuracy was recently reported for the three-dimensional (3D) computerised planning of total hip arthroplasty (THA), comparing well with navigation regarding leg length and femoral offset. However, there is no randomised study comparing 3D preoperative planning with conventional 2D templating in terms of accuracy and clinical relevance.
Hypothesis: The 3D preoperative planning has a higher accuracy than the conventional 2D preoperative templating regarding the implants size and their positioning.
Patients and methods: A prospective comparative randomised study was carried out from 2008 to 2009, including two groups of 30 patients who underwent THA for primary osteoarthritis. One surgeon performed all the surgical procedures using a minimally invasive direct anterior approach. In one group, the planning was made on calibrated X-rays using 2D templates. In the other group, a CT-scan based 3D computerised planning was performed with dedicated software. The reconstructed hip final anatomy was compared postoperatively to the preoperative planning and the accuracy was expressed as the mean difference (± SD) between the planned positioning and the final positioning of the implants.
Results: The prediction rate for the stem and the cup sizes were respectively of 100% and 96% in the 3D group versus 43% for both components in the 2D group. When combining both components, the prediction rate was 96% in the 3D group versus 16% in the 2D group. In the 3D group, a high accuracy was achieved for the planning of the leg length (−1.8 ± 3.6 mm ranging from −8 to + 4 mm) and the femoral offset (−0.07 ± 2.7 mm ranging from −5 to + 4 mm) versus 1.37 ± 6.4 mm ranging from −9 to 13 mm and 0.33 ± 5.7 mm (−16 to 11 mm) in the 2D templating group ($P < 0.0001$).

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Discussion: The 3D planning gives a higher accuracy than conventional 2D templating in forecasting the size of cup and the stem. This contributes to the prediction for leg length and offset that is more reliable with the 3D technique. This study suggests that 3D planning CT-scan data is an attractive alternative to navigation to restore these parameters. The high accuracy achieved by a low-experience surgeon suggests that 3D planning may help shorten the learning curve when using the minimally invasive direct anterior approach.
Level of evidence: Level III low-powered prospective randomized trial.

Introduction

The leg length and the femoral offset should be restored accurately after total hip arthroplasty (THA) in order to avoid dislocation and limping [1—5], to achieve good functional outcomes and high long-term survival rates [6]. However, the leg length and the femoral offset may not be restored simultaneously in up to 32% of cases [1]. According to the literature, when using cementless components, a lower limb discrepancy (LLD) above 1 cm may be found in up to 62% of patients [7], generating patient dissatisfaction, lower clinical scores and sometimes legal problems for the surgeon who carried out the procedure.

Some authors [8] proposed to use navigation in order to avoid LLD and to accurately restore the offset. However, navigation results in longer operating time and an extra cost; therefore only a small number of hip surgeons use it. Recently, Sariali et al. [9] reported a high accuracy for hip anatomy restoration when using a novel three-dimensional (3D) CT-scan based technique for preoperative planning, with results comparing well with navigation for the leg length and the femoral offset restoration accuracy [8]. However, the 2D templating remains the gold standard technique all over the world despite the lower accuracy reported with cementless components [10—14] comparatively to cemented implants [15—17].

To the best of our knowledge, there is no randomised study comparing the 3D planning to the 2D templating regarding the accuracy of the preoperative planning. Our hypothesis was that this new 3D technique was significantly more accurate than the conventional 2D templating technique for the preoperative planning of cementless components, especially regarding the implants size and position.

Patients and methods

Patients

A prospective comparative randomised study was performed in our department from January 2008 to July 2009 and included 60 consecutive patients who underwent THA for primary osteoarthritis. Indeed, according to the literature, the expected accuracy for size components prediction was about 90% for the 3D planning [9] versus an average rate of 45% [10—15,18] for the conventional 2D templating technique. With an alpha level of 0.05 and a power of 80%, a minimum of 25 patients would be needed in each group.

One low-experience surgeon (ESA) performed all the surgical procedures through a direct anterior approach using an orthopaedic traction table [19]. The preoperative planning technique and the implanted stem were randomised at the time of the consultancy. Indeed, the 3D planning was only available with the SPS modular component (Symbios, Yverdon, Switzerland), which is a cementless anatomic modular neck stem [9]. Conversely, in the 2D group we used our current stem (Global, Ceramconcept, Newark, New-Jersey, USA), which is a cementless straight quadrangular stem. Delta Ceramic-on-ceramic heads and liners were used in all the patients (Ceramtec, Plochingen, Germany). Thirty patients were included in each group. There was no significant difference between the two groups for the age, the gender, and the body mass index (Table 1).

Two-dimensional planning methodology

In the 2D group, all the patients underwent AP views of the pelvis and the hip and a true lateral view of the hip, before surgery and at 6 weeks postoperatively. All the X-rays were performed in our department on the same calibrated X-rays machine, with the patient in a standardised standing position. The radiographic magnification coefficient was measured on five pelvis radiographies and was found to be 1.15 ± 0.02 (1.12—1.18). Templates with the same magnification coefficient (1.15) were used for the 2D preoperative planning and the planned components were drawn on the films (Fig. 1A). The height from the top of the lesser trochanter to the planned neck-osteotomy plane was measured and used during surgery to perform the osteotomy. Both X-rays (preoperative and at 6 weeks follow up) were digitalized and the final hip anatomy was compared to the planned anatomy using the Imagika™ software (ViewTeck, Saint Maur, France) (Fig. 1A and B). Both X-rays were calibrated using the femoral head diameter of the controlateral hip. The following parameters were assessed: the coordinates of the acetabular cup center related to the U landmarks, the femoral offset and the height of the femoral head center from the top of the greater trochanter. The accuracy of the hip anatomy restoration was expressed as the difference ± standard deviation, between the planned position and the final position.

The three-dimensional planning methodology

In the 3D group, a low dose protocol CT-scan [20] was performed and the preoperative planning was achieved by the surgeon (ESA) with the Hip-Plan™ software [21] (Symbios, Yverdon, Switzerland). The 3D-cup template was placed relative to the anterior and posterior acetabular walls as well as to the supero-lateral acetabular margin, so that the removal of the supportive subchondral bone was minimal and the

Table 1 Clinical data for the two groups.

Group	Age (years)	Sex Ratio (M/F)	Height (cm)	Weight (kg)	BMI (kg/m^2)
3D planning	60 ± 15 (23—87)	21 M/9 F	170 ± 9.3 (150—185)	78.1 ± 14 (50—99)	27.1 ± 3.7 (19.5—34.3)
2D planning	57.2 ± 13 (27—77)	23 M/7 F	170 ± 7.7 (157—185)	74.7 ± 21.75 (50—112)	25.8 ± 6.7 (18.6—45.4)

centre of rotation of the hip was closely restored. The goal was to restore the native acetabular anteversion. The stem size was chosen to maximize both fit and fill in the femoral metaphysis. The final cranial-caudal position of the stem will be reached when this femoral implant will block, reflecting a good fit with the femoral canal. To determine this cranial-caudal blocking level of the stem, corresponding to a safe reaming procedure, a colour image mode reflecting the density of the bone in contact with the stem was used (Fig. 2). This colour grading was calculated using the Hounsfield density from CT-scan. To achieve a good primary mechanical stability, authors assumed that the stem should be in contact with a highly dense bone at least on the stem lateral flare and the calcar and that the cup should be in contact with a highly dense bone at least on both the anterior and the posterior horns. Finally, the distances from the neck-osteotomy plane to the top of the lesser trochanter and to the top of the greater trochanter were measured in order to check the level to obtain the adequate fit level during the surgery (Fig. 3). A view in the neck-osteotomy plane was given to the surgeon in order to visually control the position of the stem during the surgical procedure and to determine the supportive cancellous to keep in order to achieve a good rotational stem stability and to check the final femoral anteversion (Fig. 4). Once the cup and the stem were implanted, modular necks and heads were used in order to restore the extra-medullar anatomy, especially the limb length and the offset. Neck modularity allowed three different neck-shaft angles (8° varus, straight, 8° valgus), three anteversion angles (10° retroversion, 0°, 10° anteversion)

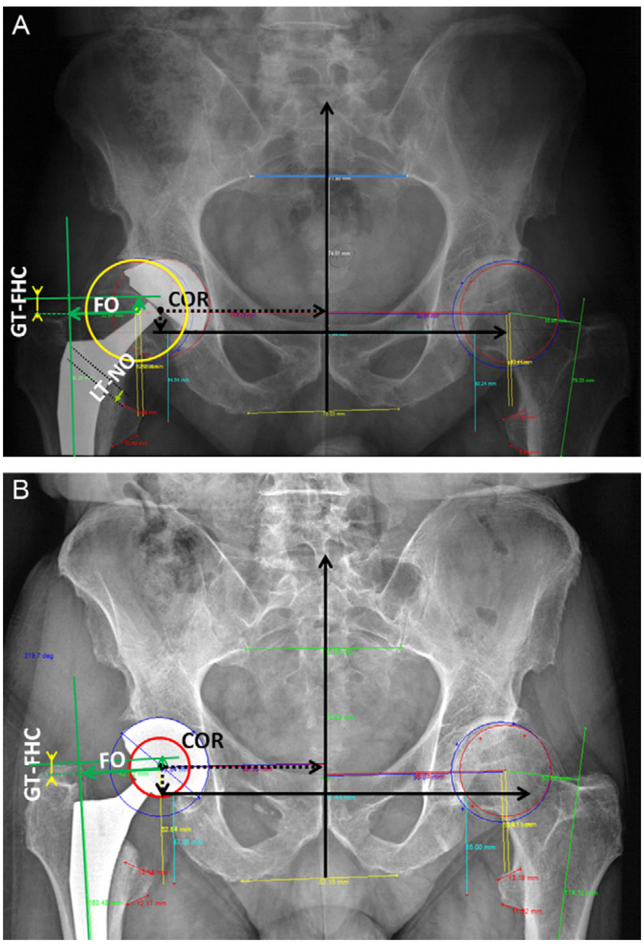

Figure 1 The 2D preoperative conventional templating. A. The planned components were drawn on the films. The radiographies were digitalised and the planned hip anatomy was analyzed with Imagika™ software: the hip center of rotation (COR), the femoral offset (FO), the height from the top of the greater trochanter to the femoral head center (GT-FHC). The height from the top of the lesser trochanter to the neck-osteotomy (LTNO) plane was measured and used to guide the surgical procedure. (native-FO = 39 mm, planned-FO = 44 mm; native-COR = 102 mm/55 mm, planned-COR = 92 mm/60 mm; native GT-FHC = −7 mm, planned GT-FHC = −9 mm; planned LTNO = 7 mm). B. Radiographies performed 6 weeks postoperatively were analysed to compare the final hip anatomy to the planning. (Final FO = 42.5 mm; fnal COR = 91 mm/62 mm;fnal GT-FHC = −10 mm, fnal LTNO = 7 mm.)

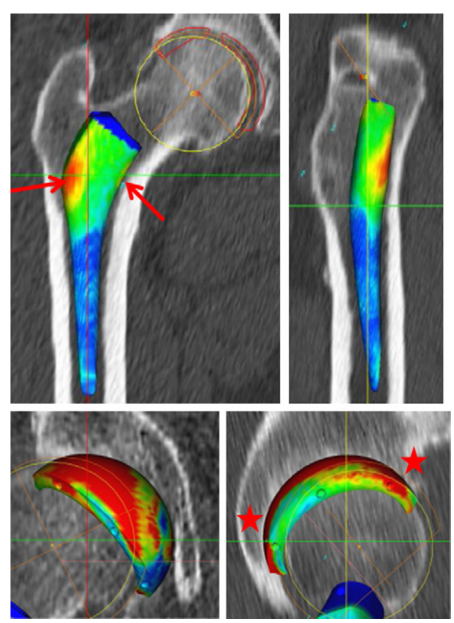

Figure 2 The 3D preoperative planning. To achieve a good primary mechanical stability, authors assumed that the stem should be in contact with a highly dense bone at least on the stem lateral flare and the calcar (arrow) and that the cup should be in contact with a highly dense bone at least on both anterior and posterior horns (stars).

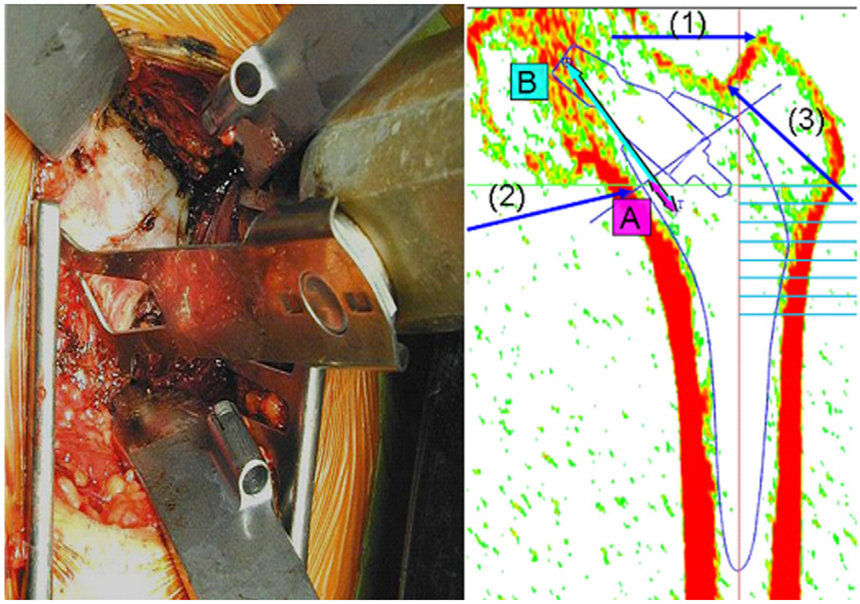

Figure 3 The distances from the neck-osteotomy plane to the top of the greater trochanter (1), to the top of the lesser trochanter (2) and to the digital fossea (3) were measured in order to check the seating level of the stem during the surgery.

and two different lengths for each neck (short, long). The straight neck corresponded to a 134° neck-shaft angle. The goal was to restore the femoral offset and the height of the femoral head center from the top of the greater trochanter. The planned stem anteversion was the femoral anteversion because no dislocated hip was included. For the femoral head, three lengths could be used: −4 mm, 0, and +4 mm. Reference landmarks were determined in order to guide the surgeon for the neck-osteotomy. For this purpose, the distances from the neck-osteotomy plane to the top of the greater trochanter, the digital fossea and the top of the lesser trochanter were measured (Fig. 3).

In order to compare the planned anatomical parameters and the final achieved parameters, the same Cartesian reference landmark was used. For this, a matching of the preoperative and the post operative CT-scans was performed with the Hip-plan™ software by aligning separately the pelvis and then the femoral bone landmarks (Fig. 5). The same parameters were evaluated: the coordinates of the acetabular cup center, the femoral offset and the height of the femoral head centre from the top of the greater trochanter. The accuracy of the hip anatomy restoration was expressed as the difference ± standard deviation, between the planned position and the final position. The duration of the 3D planning was about 10 to 15 mn.

Statistical analysis

The accuracy of the planning was compared between the two groups. The accuracy was calculated separately for 2D and 3D planning by comparing the planned position and

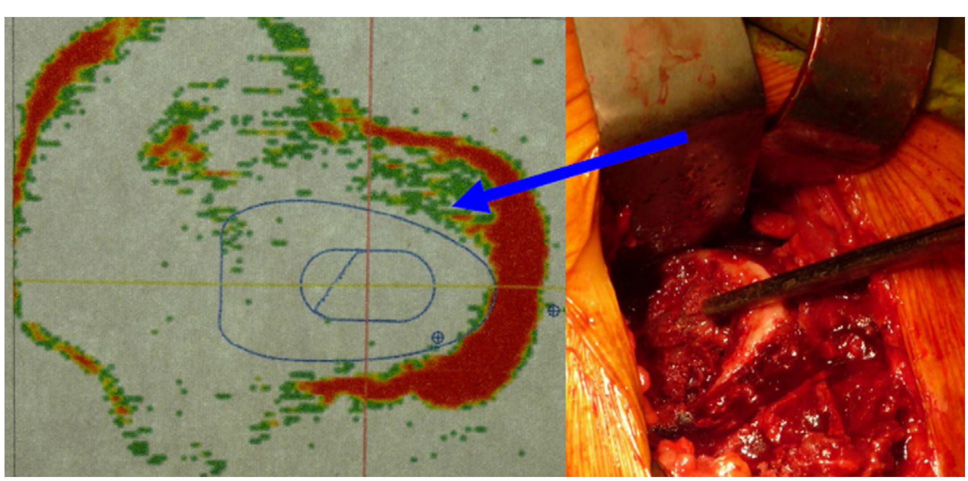

Figure 4 A view of the neck-osteotomy plane was given to the surgeon in order to visually control the position of the stem during the rasping procedure and to determine the supportive cancellous (blue arrow) to keep in order to achieve good rotational stem stability and to check the final femoral anteversion.

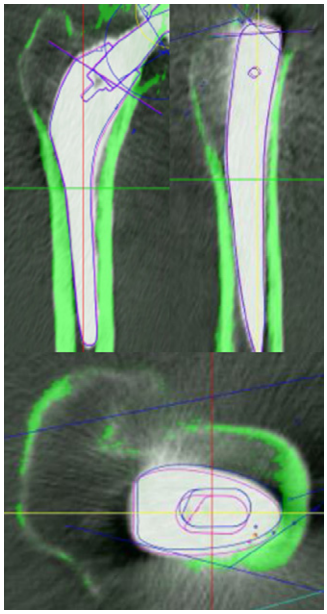

Figure 5 In order to compare the planned anatomical parameters and the clinical outcome, a matching of the preoperative and the post operative CT-scans was performed with the Hip-Plan™ software by separately aligning the pelvis and then the femoral bone landmarks. The planned components are blue and the final implants are pink.

the final position, but there was no comparison between native hip's anatomy and the reconstructed hip. For this purpose, the distribution of the variables was tested for normality using the Ryan-Joiner and Shapiro-Wilk tests. For normally distributed variables, when the two groups had the same variances, differences were analysed using Student's *t*-test. For non-normally distributed variables or normally distributed variables with different variances, we used the Mann and Whittney test. A *P* value of less than 0.05 was considered to be significant.

Results

In the 2D group, the final implanted components were the same as the one planned in 43% of patients for the stem, 43% for the cup and 66% for the head. In the 3D group the accuracy was twice as high with 96% for the cup, 100% for the stem and 93% for the head (Fig. 6). Interestingly, when combining both the stem and the cup, the precision was of 96% in the 3D group versus 16% in the 2D group.

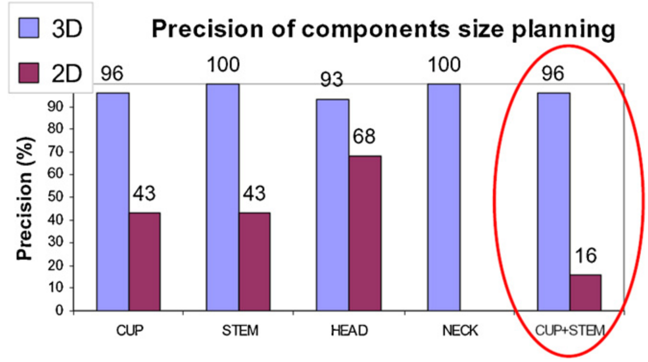

Figure 6 In the 3D group the accuracy was twice higher with 96% for the cup, 100% for the stem and 93% for the head.

The height of the femoral head centre from the top of the greater trochanter, and the femoral offset were planned with a significantly higher precision in the 3D group. Indeed, cranio-caudally, the femoral head centre was planned with a precision of -0.07 ± 2.7 mm (−5 to +4 mm) in the 3D group versus 0.33 ± 5.7 mm (−16 to 11 mm) in the 2D group ($P < 0.0001$). Medio-laterally, the femoral offset was planned with a precision of 1.3 ± 2.6 mm (−4 to +6 mm) in the 3D group versus -0.92 ± 5.7 mm (−13 to +9 mm) in the 2D group ($P < 0.001$) (Fig. 7).

The centre of rotation (COR) was planned with a significantly higher precision in the 3D group. Indeed, cranio-caudally, the COR was planned with a precision of 1.7 ± 3.3 mm (−10 to +5 mm) in the 3D group versus 1.7 ± 5 mm (−9 to +12 mm) in the 2D group ($P < 0.0001$). Medio-laterally, the COR was planned with a precision of -0.27 ± 3.3 mm (−9 to +5 mm) in the 3D group versus -2.4 ± 6 mm (−16 to + 11 mm) in the 2D group ($P < 0.001$) (Fig. 8).

In total, the leg length was planned with a twice as high accuracy in the 3D group (-1.8 ± 3.6 mm ranging from −8 to

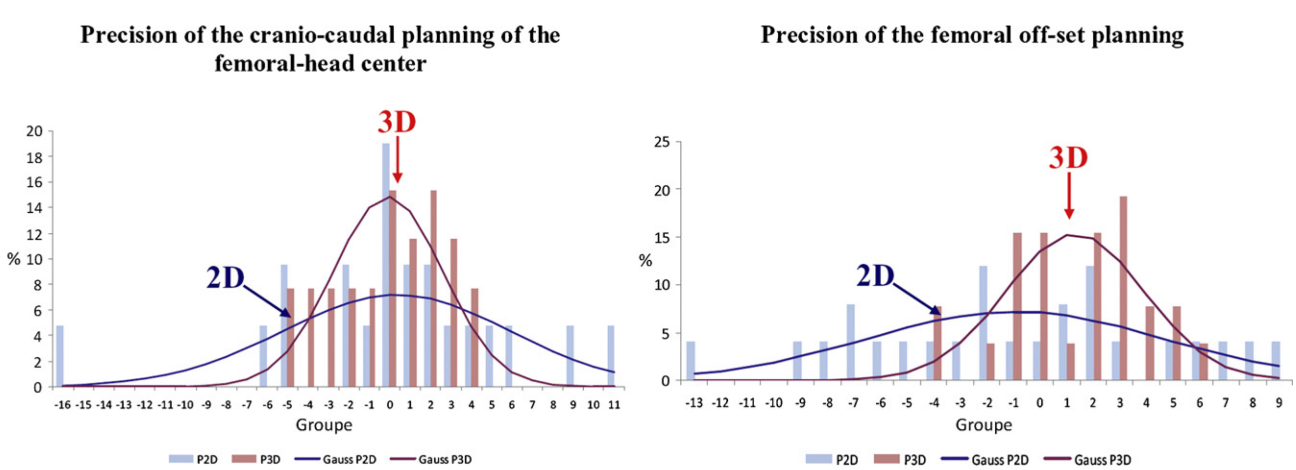

Figure 7 Accuracy of the femoral head centre planning: height from the top of the greater trochanter and femoral offset.

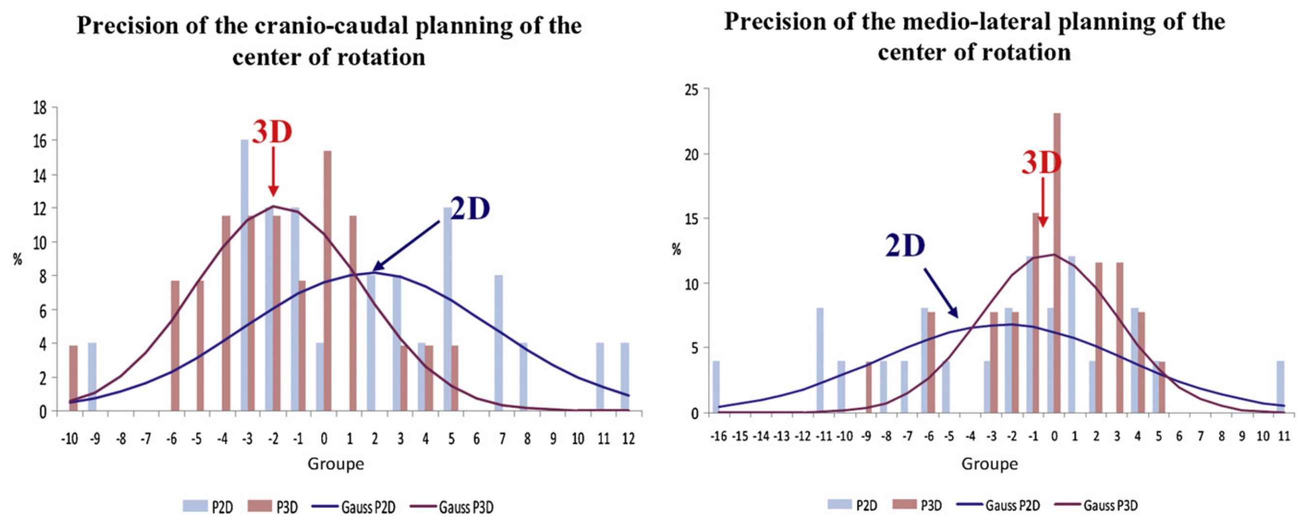

Figure 8 Accuracy of the hip rotation centre planning, in the cranio-caudal and the medio-lateral directions.

+4 mm) as in the 2D group (1.37 ± 6.4 mm ranging from −9 to 13 mm) ($P < 0.0001$). Interestingly, there was no outlier in the 3D group above 8 mm of error in leg length restoration.

Discussion

The main finding of this study was that the 3D planning was more accurate than the conventional templating regarding the components size prediction and the accuracy of the hip reconstruction planning. The results compared well with the literature for both techniques [9—14]. Indeed, for the 2D templating, the accuracy rate for uncemented components is much lower than the rates reported for cemented THA [15,16] as it varies according to the authors, ranging from 20% to 70% [10,12—14,22], with an average accuracy of about 45%. Concerning the 3D planning, we previously [9] reported an accuracy of about 93% for the stem and 86% for the cup, similar to the current findings.

The major limitation of the study was that the implanted stem was different between the two groups. This disparity was due to the fact that the 3D technique was available only with the SPS modular stem and the operator did not want to use a modular neck unless an accurate preoperative technique was used especially regarding the final stem position. Indeed, the optimal neck-shaft angle depends on the level where the stem is seated. However, we did not compare the ability to restore the hip anatomy but the difference between the final value and the planned value of the implants size and their position. Another limitation was that the SPS stem had a modular neck. However, this difference did not bias the results as the authors compared the final position of the implants to the planned position and not to the patient's preoperative anatomy. Therefore, the planning precision was assessed and not the ability to restore the patient's anatomy.

Conn et al. [22] showed that the use of a ten-pence piece as a radiopaque marker to assist with magnification improved the templating accuracy regarding the components size prediction, as it increased from 59.5% to 68.8%, but remained much lower than the accuracy of the 3D planning. Gamble et al. [11] reported an accuracy of 38% for the cup and 40% for the stem when using digital templating and interestingly, there was no major difference with the standard onlay technique, with an accuracy of, respectively, 20% for the cup and 40% for the femur. These findings suggest that errors in preoperative templating are not entirely due to the inaccuracy of the radiographic magnification.

This lack of accuracy for the 2D templating is probably related to the fact that the hip anatomy is not accurately analyzed on radiographies, especially for the femur, as reported by Eckrich et al. [23]. Indeed, two factors may influence the introduction and the final position of the stem inside the femoral canal: the bone hardness and the proximal femur torsion, which varies from 0° to 50° even if no major dysplasia is involved [6,21]. These two factors are not available on plain radiographies and are indeed of high importance for cementless THA.

The final cranio-caudal blockage level of the stem cannot be accurately predicted without taking into consideration the 3D volume of the femur and the bone hardness. This may explain why leg length discrepancy (LLD) is so frequent after THA when using cementless components. Indeed, a LLD about 1 cm was reported in up to 56% of patients by Ahmad et al. [24], and 62% by Konyves et al. [7], and this rate did not vary according to the surgeon experience. Interestingly, Konyves et al. [7] found that in 98% of patients, lengthening occurred in the femoral component, highlighting the crucial importance of an accurate stem planning. In our experience, an increment of one size in the femoral stem may generate a limb lengthening of up to 1 cm, especially in young patients with a hard cancellous bone. Therefore, the precision within one size reported by some authors [17], may not be reliable for the stem planning, as one size difference may generate substantial lengthening. For this reason, some authors prefer to use cemented stems, as LLD is less frequent and the precision of the planning is much higher [15,16]. In this point of view, the use of modular neck is an attractive option for an accurate hip reconstruction [9], on condition an accurate planning is performed beforehand.

As recently reported [9,21], one of the main interests of the 3D planning is the anticipation of the surgical difficulties allowing consequently a safer procedure. In fact, the 3D planning permits the analysis of the torsional abnormalities especially the femoral helitorsion [6], a better assessment of the femoral offset [25] which may not be correlated to the femur size and the bone density which is crucial to assess when using cementless components. However, the main goal of this study was to assess the precision of the planning regarding the components size and position. Indeed, when using modular stems, the optimal neck depends on the stem size, its position relatively to the femur and the center of the cup. Therefore, the use of modular necks requires an accurate planning technique in order to avoid a misuse of the neck modularity and the inherent risk.

The precision for the leg length planning was of 1.8 ± 3.6 mm equivalent to recently reported results for navigation [8,26,27]. Kitada et al. [8] found a mean difference of 1.3 ± 4.1 mm between the planned lengthening and the final clinical results. It seems difficult to achieve better results given the fact that the saw used for the neck-osteotomy has a width of 1.5 mm, which may generate an error of 3 mm for the osteotomy level. For this reason we postulate that the 3D planning is an attractive option to navigation in order to improve the accuracy of the hip reconstruction after THA, especially regarding the leg length and the offset.

The precision of the 3D planning compared very well with the previously reported results for highly experienced hip surgeons [9], despite the fact that the surgical procedures were achieved by a less-experience surgeon. This finding suggests that the 3D surgical planning may achieve a shorter learning curve especially when using the direct minimal invasive anterior approach. Indeed, high complication rates were reported for this technique and more frequently at the beginning of the practice [19], including femoral perforations and greater trochanter fractures [19,28]. This high complication rate on the femoral side may be due to poor exposure of the femur but also to poor analysis of the femoral intracanalar volume, which may explain why, these femoral fractures still happen even with highly experienced surgeons [28]. In our experience these fractures may happen in case of a severe femoral varus or valgus and an oversized internal femoral calcar septum [29]. This constant intra femoral bony spur prevents a rasping in a correct alignment and it tends to push forward the rasps or the stem generating, consequently, a risk of an anterior fracture of the proximal femur. This spur is difficult to detect preoperatively on standard radiographies. Seng et al. [30] found the learning curve of the direct anterior approach to be around 40 cases but they did not report the accuracy of the hip reconstruction and how the surgeon experience may affect this accuracy. Some authors [28] suggest the use of fluoroscopy to aid in implant positioning during the surgical procedure. However, these authors still have a high rate of femoral fractures (three perforations, 19 trochanter, three perforations in 800 patients) despite this fluoroscopic guidance [28], which is really a serious concern for us regarding the global cumulative radiation for the surgeon.

Regarding the CT-scan, we now use a specific low radiation protocol [20], corresponding to 5 mSv, which is quite equivalent to a hip X-rays routine protocol (2.7 mSv). The gain in accuracy and safety justifies the use of a CT-scan for THA planning particularly as it is associated with a slight increase of radiation exposure in comparison to conventional radiographs and low per-patient costs [20]. In practice, sessions co-organized with radiologists, are booked to perform the low dose CT-scans. The CD is given to the patient who brings it at the time of the consultation with the anaesthesiologist. The surgeon performs the 3D planning as soon as possible in order to detect eventual surgical difficulties. Indeed, in some cases of severe torsional abnormalities or high offset, we prefer the use of custom stems rather than 16° varus necks, in order to avoid the risk of neck fracture.

The 3D planning takes 10 to 15 minutes to be performed. However, some algorithms are now automated such as the determination of the anterior pelvic plane, the femoral frame and the anatomic landmarks. In the future, the whole process will be automated and a proposition of 3D planning will be performed, the operator may accept or adapt the proposed planning. An automated algorithm for impingement detection, including neck-cup and bony impingements, is now being developed. The impingement simulation may allow in the future a dynamic planning, similarly to what have been reported for the dynamic navigation [31].

However, the higher accuracy obtained with the 3D preoperative technique may not be associated to better clinical outcomes. Clinical studies are needed to analyze the clinical relevance of such accuracy, especially regarding gait pattern because the clinical scores may not be sensitive enough to show clinical functional differences.

Conclusion

The 3D computerised preoperative planning allows achieving a higher accuracy than conventional 2D templating for THA preoperative planning. The reported accuracy for 3D planning compared very well with previously reported results for navigation regarding leg length and offset. This technique appears to be an attractive alternative to navigation especially that it allows to detect, preoperatively, the difficulties likely to be encountered and to solve them beforehand by optimizing the choice of the implants. The use of a CT-scan for preoperative planning is not a concern as the radiation dose may be very low when using specific protocols.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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The Hip-Plan Software was offered by Symbios Company to the department of orthopaedic surgery in order to perform the three-dimensional planning of the SPS stem.

References

[1] Asayama I, Chamnongkich S, Simpson K, Kinsey TL, Mahoney OM. Reconstructed hip joint position and abductor muscle strength after total hip arthroplasty. J Arthroplasty 2005;20:414—20.

[2] Bourne R, Rorabeck C. Soft tissue balancing: the hip. J Arthroplasty 2002;4:17—22.

[3] Downing N, Clark D, Hutchinson J, Colclough K, Howard PW. Hip abductor strength following total hip arthroplasty: a

prospective comparison of the posterior and lateral approach in 100 patients. Acta Orthop Scand 2001;72:215—20.
[4] Kiyama T, Naito M, Shinoda T, Maeyama A. Hip abductor strengths after total hip arthroplasty via the lateral and posterolateral approaches. J Arthroplasty 2010;25:76—80.
[5] McGrory B, Morrey B, Cahalan T, An KN, Cabanela ME. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. J Bone Joint Surg Br 1995;77:865—9.
[6] Flecher X, Pearce O, Parrate S, Aubaniac JM, Argenson JN. Custom cementless stem improves hip function in young patients at 15 years folluw-up. Clin Orthop Relat Res 2010;468: 747—55.
[7] Konyves A, Bannister G. The importance of leg length discrepancy ater total hip arthroplasty. J Bone Joint Surg Br 2005;87:155—7.
[8] Kitada M, Nakamura N, Iwana D, Kakimoto A, Nishii T, Sugano N. Evaluation of the accuracy of computed tomography-based navigation for femoral stem orientation and leg length discrepancy. J Arthroplasty 2011;26(5):674—9. Epub 2010.
[9] Sariali E, Mouttet A, Pasquier G, Durante E, Catone Y. Accuracy of reconstruction of the hip using computerised three-dimensional preoperative planning and a cementless modular neck stem. J Bone Joint Surg Br 2009;91:333—40.
[10] Carter L, Young T. Determination of accuracy of preoperative templating of noncemented femoral prostheses. J Arthroplasty 1995;10:507—13.
[11] Gamble P, De Beer J, Petrucelli D, Winemaker M. The accuracy of digital templating in uncemented total hip arthroplasty. J Arthroplasty 2010;25:529—32.
[12] González Della Valle A, Comba F, Taveras N, Salvati EA. The utility and precision of analogue and digital preoperative planning for total ip arthroplasty. Int Orthop 2008;32:289—94.
[13] Knight J. Preoperative planning for total hip arthroplasty. Quantitating its utility and precision. J Arthroplasty 1992;7:403—9.
[14] Linclau L, Peene P. Radiological aspects in preoperative planning and postoperative assessment of cementless total hip arthroplasty. Acta Orthop Bg 1993;59:163—7.
[15] Eggli S, Muller M. The value of preoperative planning for total hip arthroplasty. J Bone Joint Surg Br 1998;80:382—90.
[16] González Della Valle A, Slullitel G, Piccaluga F, Salvati EA. The precision and usefulness of preoperative planning for cemented and hybrid primary total hip arthroplasty. J Arthroplasty 2005;20:51—8.
[17] Lorio R, Siegel J, Specht LM, Tilzey JF, Hartman A, Healy WL. A comparison of acetate vs. digital templating for preoperative planning of total hip arthroplasty: is digital templating accurate and safe? J Arthroplasty 2009;24:175—9.
[18] Oddy J, Jones J, Pendegrass C, Pilling JR, Wimhurst JA. Assessment of reproducibility and accuracy in templating hybrid total hip arthroplasty using digital radiographs. J Bone Joint Surg Br 2006;88:581—5.
[19] Sariali E, Leonard P, Mamoudy P. Dislocation after total hip arthroplasty using the Hueter anterior approach. J Arthroplasty 2008;23:266—72.
[20] Huppertz A, Radmer S, Asbach P, et al. Computed tomography for preoperative planning in minimal invasive total hip arthroplasty: Radiation exposure and cost analysis. Eur J Radiology 2011;78:406—13.
[21] Sariali E, Mouttet A, Pasquier G, Durante E. Three dimensionnal hip anatomy in osteoarthritis. Analysis of the femoral offset. J Arthroplasty 2009;24:990—7.
[22] Conn K, Clarke M, Hallett J. A simple guide to determine the magnification of radiographs and to improve the accuracy of preoperative templating. J Bone Joint Surg Br 2002;84:269—72.
[23] Eckrich S, Noble P, Tullos H. Effects of rotation on the radiographic appearance of the femoral canal. J Arthroplasty 1994;9(4):419—26.
[24] Ahmad R, Sharma V, Sandhu H, Bishay M. Leg length discrepancy in total hip arthroplasty with the use of cemented and uncemented femoral stems. A prospective radiological study. Hip Int 2009;19:264—7.
[25] Pasquier G, Ducharne G, Ali ES, Giraud F, Mouttet A, Durante E. Total Hip arthroplasty offset measurement: is CT-scan the most accurate option? Orthop Traumatol Surg Res 2010;96:367—75.
[26] Manzotti A, Cerveri P, De Momi E, Pullen C, Confalonieri N. Does computer-assisted surgery benefit leg length restoration in total hip replacement? Navigation versus conventional freehand. Int Orthop 2011;35:19—24.
[27] Nishio S, Fukunishi S, Fukui T, Fujihara Y, Yoshiya S. Adjustment of leg length using imageless navigation THA software without a femoral tracker. J Orthop Sci 2011;16:171—6.
[28] Jewett BA, Collis DK. High complication rate with anterior total hip arthroplasties on a fracture table. Clin Orthop Relat Res 2011;469:503—7.
[29] Decking J, Decking R, Schoellner C, Drees P, Eckardt A. The internal calcar septum and its contact with the virtual stem in THR: a computer tomographic evaluation. Acta Orthop Scand 2003;74:542—6.
[30] Seng B, Brend K, Ajluni A, Lombardi Jr AV. Anterior-supine minimally invasive total hip arthroplasty: defining the learning curve. Orthop Clin North Am 2009;40:343—50.
[31] Laffargue P, Pinoit Y, Tabutin J, Giraud F, Puget J, Migaud H. Computer-assisted positioning of the acetabular cup for total hip arthroplasty based on joint kinematics without prior imaging: preliminary results with computed tomographic assessment. Rev Chir Orthop 2006;92:316—25.