Imageless computer navigation without pre-operative templating may lead to malpreparation of the femoral head in hip resurfacing

The computed neck-shaft angle and the size of the femoral component were recorded in 100 consecutive hip resurfacings using imageless computer-navigation and compared with the angle measured before operation and with actual component implanted. The reliability of the registration was further analysed using ten cadaver femora. The mean absolute difference between the measured and navigated neck-shaft angle was 16.3° (0° to 52°).

Navigation underestimated the measured neck-shaft angle in 38 patients and the correct implant size in 11. Registration of the cadaver femora tended to overestimate the correct implant size and provided a low level of repeatability in computing the neck-shaft angle.

Prudent pre-operative planning is advisable for use in conjunction with imageless navigation since misleading information may be registered intraoperatively, which could lead to inappropriate sizing and positioning of the femoral component in hip resurfacing.

Hip resurfacing arthroplasty offers an alternative to total hip replacement in the young and active adult with end-stage osteoarthritis. The benefits of this procedure include preservation of femoral bone stock and recreation of the native anatomy, but the risk of fracture of the femoral neck and of inadequate fixation of the implant persist. Female gender, short stature, obesity, poor bone quality, large cystic defects, excessive removal of the soft tissue surrounding the femoral neck, notching of the superior cortex of the femoral neck, alignment of the implant in relative varus and exposure of reamed cancellous bone all influence the likelihood of failure. Some of these factors are introduced by the surgeon during preparation of the femoral head.

Conventional preparation of the femoral head is performed using mechanical jigs secured manually to the proximal femur to allow placement of the initial guide-wire. The surgeon aligns this jig by inspection which is error. Computer navigation shows promise in increasing the accuracy of insertion of the initial guide-wire, improving the quality of preparation of the femoral head and the final placement of the femoral component.

While computer navigation may be a powerful tool for minimising poor preparation of the femoral head, the use of imageless computer navigation in the absence of a thorough pre-operative template may lead to less accurate positioning of the component and a potentially poorer outcome. In this study we have compared the neck-shaft angle and size of the femoral component as measured by computer navigation with the neck-shaft angle measured pre-operatively and the actual size of the implanted femoral component.

Patients and Methods

Between May 2007 and September 2008, 100 consecutive navigated hip resurfacings were performed by a single surgeon (EHS). There were 80 men and 20 women with a mean age of 51.9 years (26 to 82). The number of resurfacings was divided evenly between left and right hips. Clinical diagnoses included primary osteoarthritis (OA) in 92 patients, OA secondary to developmental dysplasia in two patients, OA secondary to slipped capital femoral epiphysis in one and avascular necrosis of the femoral head in five.

Operative procedure. Before operation templating was performed using digital anteroposterior (AP) unilateral radiographs of the hip (Fig. 1). A standard protocol was used in which the patient was placed in the AP neutral position with no femoral rotation. The source-to-image distance was 100 cm centred over the proximal femur. The axis of the femoral shaft was drawn as a line from the most distal visible diaphyseal midpoint to the piriformis fossa. A line was then drawn to bisect the isthmus of the neck and extended towards the lateral cortex, intersecting the axis of the femoral shaft.
This was the neck axis, and the angle subtended by the axes of the neck and shaft was defined as the neck-shaft angle. The size of the component was then chosen with the femoral component template positioned in an appropriate amount of relative valgus. This position was represented by the angle which the stem of the femoral component made with the axis of the femoral shaft and was referred to as the stem-shaft angle. The intention was to produce a stem-shaft angle in approximately 5° to 10° of relative valgus as has been recommended in the literature and shown to limit the tension on the superior femoral neck.9-14 The values of the neck-shaft and stem-shaft angles were recorded for use during intraoperative navigation.

At operation the patients were placed in the lateral decubitus position and a posterolateral approach was used. The femoral head was prepared according to the standard protocol with the use of imageless computer navigation for placement of the initial guide-wire. A Birmingham hip resurfacing arthroplasty (Smith and Nephew, Memphis, Tennessee) was used in all the patients.

**Imageless computer navigation.** Imageless computer navigation uses infrared camera technology to register anatomical landmarks and topography to create a patient-specific proximal femoral model. The Vector Vision SR 1.0 imageless navigation system (BrainLAB, Heimstetten, Germany) was used intraoperatively to plan the position of the guide and to insert the initial femoral guide-wire. The method of patient registration has been previously described.7 The navigation system acquires several anatomical landmarks to determine the anatomical axes. The medial and lateral epicondylar eminences and the piriformis fossa delineate the diaphyseal axis. The superior head-neck junction is selected and the surfaces of the femoral head and neck are digitised. The diameter of the femoral head determines the size of the computed implant and the head-neck junction is used to situate the implant initially. The system uses point clusters acquired on the outline of the superior and inferior femoral neck to determine the neck-shaft angle by fitting a plane to each cloud of points. A mid-plane between the two is calculated and the inclination of the mid-plane to the diaphyseal axis is the computed neck-shaft angle.

On completion of this registration, a patient-specific model is created. The system performs a check and adjusts the implant size to ensure that the femoral neck will not be notched. The system calculates a neck-shaft angle as well as a recommended size of femoral component which can be accepted or modified using the surgical planning screen before drilling the guide-wire into the femoral head (Fig. 2). Once the surgical plan is agreed, a navigated hand-held drill guide is used to control placement of the initial guide-wire. The remainder of the standard protocol is followed for preparation of the femoral head.

**Cadaver registration.** In order to investigate the relative accuracy and reliability of the registration process, ten denuded adult left femora were obtained from cadavers (Pacific Research Laboratories, Vashon, Washington). Four fellowship-trained orthopaedic surgeons, familiar with navigation, registered the ten cadaver femora three times each for a total of 30 registrations performed by each surgeon. The femora were prepared with a static array fixed in the lesser trochanter and positioned in a maximal internal rotation and adduction, simulating the operative position of the femur (Fig. 3). The surgeons were instructed to acquire anatomical landmarks according to the landmark positions indicated on the navigation screen and to register anatomical areas by distributing points randomly throughout the areas indicated by the navigation prompts. The computed neck-shaft angle and the implant size were recorded for statistical analysis. Before registration, a digital AP radiograph of each femur was obtained. The femora were positioned with the plane of the neck parallel to the cassette of the radiograph with a source-to-image distance of 100 cm centred over the neck. Radiographs were digitally measured for the neck-shaft angle by the same observer (MO) who performed all the pre-operative templating in the clinical series. Additionally, this observer assessed each femur for implant size using a neck-measuring gauge before registration. The surgeons were blinded to the measurements of the neck-shaft angle and neck-gauge before performing the registrations. A second observer (MC) repeated the measurements on the ten femora to determine the reliability of determination of the neck-shaft angle.
Statistical analysis. For the analysis of differences within and between surgeons, Microsoft Excel (Microsoft Corp, Redmond, Washington) and the statistical software package SPSS version 13 (SPSS Inc., Chicago, Illinois) were used. One-way analysis of variance (ANOVA) with Tukey post hoc analysis was performed comparing the differences in the computed neck-shaft angle between surgeons. A Pearson chi-squared analysis was used to compare categorical data for the computed implant size between surgeons for each femur. A p-value ≤ 0.05 was considered to be significant. An intraclass correlation coefficient was computed to estimate the intra- and inter-surgeon reliability in the computed neck-shaft angle and the reliability between the observers in the measurement of the angle in the ten cadaver femora. An intraclass correlation coefficient indicates the proportion of the total variance in measurements that can be explained by differences between individuals. Intraclass correlation coefficient values range from 0 to 1 with values greater than 0.75 considered acceptable. A two-way, absolute, random-effects model measuring single-measure reliability was used with the participating surgeons considered to be a random sample from a larger group of surgeons. A generalised kappa statistic was used to determine the reliability in computed implant size between surgeons and using the SPSS program the level of agreement for categorical data between multiple observers was calculated. This measure is analogous to the intraclass correlation coefficient used for continuous data and was interpreted according to the guidelines of Landis and Koch in evaluating the strength of agreement using the generalised kappa statistic.

Results
Pre-operative planning determined a mean neck-shaft angle of 131.7° (116° to 144°). The navigation system computed a mean neck-shaft angle of 137.5° (90° to 180°). The mean absolute difference between the pre-operatively planned and computed neck-shaft angle was 16.3° (0° to 52°). The relative range of values for the computed compared with the measured neck-shaft angle was 42° of varus to 52° of valgus (Fig. 4).

In our series, 60 computed angles were valgus, 38 varus and two equal to the pre-operatively planned neck-shaft angle. Of the 60 valgus-computed neck-shaft angles, 42 (70%) were greater than 10°. Only 16 of the computed angles were within an acceptable range of ± 3° of the measured neck-shaft angle. A varus-computed neck-shaft angle poses the danger of a varus-aligned implant. Of the 38
varus-computed neck-shaft angles, 21 (55%) were greater than 10°. The 17 remaining computed neck-shaft angles were divided with 12 of less than 5° of varus and seven of between 5° and 10° of relative varus. This latter group of relative varus-computed neck-shaft angles poses the greatest hazard for planning the alignment of an implant.

Navigation tended to overestimate the component size. In 76 of the 100 cases, a larger component than the one implanted was recommended, while in 13, the navigation software correctly recommended the size of femoral component to use. In the remaining 11 hips, the system recommended a size smaller than that implanted. While an oversized implant may reduce the risk of femoroacetabular impingement, it also leads to greater resection of acetabular bone. Conversely, an undersized femoral component may lead to notching of the neck during its preparation as well as an increased likelihood of impingement.

**Cadaver registration.** Measurement of the ten cadaver femora by digital radiographs yielded a mean neck-shaft angle of 127.5° (16° to 132°). The two observers showed good agreement in the measurement of the neck-shaft angle of the cadaver femora with a mean difference in measurement of 1.1° (SD 2.3°, intraclass correlation coefficient 0.853). Upon completion of the registrations, the mean absolute difference between the measured and computed neck-shaft angle was 5.4° (0° to 24°). The relative difference of computed to measured neck-shaft angle values ranged from 22° of varus to 24° of valgus (Fig. 5). There were significant differences in the computed neck-shaft angle between surgeons for three of the ten cadaver femora (p < 0.041). The mean difference in the computed neck-shaft angle in multiple registrations of a femur by a single surgeon was 5.5° (0° to 29°). The intra surgeon intraclass correlation coefficient for the computed neck-shaft angle was acceptable in two cases (intraclass correlation coefficient > 0.810), but poor in the remaining two (intraclass correlation coefficient < 0.246). These values indicate that a high level of repeatability was obtained for two of the participating surgeons while the navigation process was much less repeatable for

**Fig. 3**
A photograph of a cadaver femur with a static array secured in the lesser trochanter. Each femur was positioned in the bone vice and registered according to the requirements of the navigation system.

**Fig. 4**
Scatterplot of the relative difference between the measured and computed neck-shaft angle (NSA). Positive values represent relative valgus and negative values relative varus compared with the NSA measured by radiography.
the remaining two. When comparing computed neck-shaft angles across all four surgeons, the inter surgeon intraclass correlation coefficient was 0.131, indicating a very low level of repeatability in computed angle output among multiple users.

The navigation system tended to overestimate the size of the implant. Of the 120 registrations performed by the four surgeons, only 46 suggested the correct size identified by the use of the neck gauge. The remainder overestimated the size of the implant, with six oversizing the correct implant by two full sizes. There were significant differences between surgeons in the computed implant size in two of the ten femora (p < 0.029). The generalised kappa statistic was 0.155 indicating only a slight level of agreement in the computed implant size between surgeons.

Discussion

Computer-assisted navigation has a potential application in hip resurfacing arthroplasty, but our series has shown some of the problems which this technology may produce. A total of 60 navigated hip resurfacings had been conducted by the senior surgeon (EHS) before this series, thereby excluding his initial learning period.

Several mechanical factors have been identified which predispose to premature failure of the resurfaced femoral head including notching of the femoral neck and implantation with varus alignment.1,2,13,14 Navigation is supposed to minimise the occurrence of these preparatory errors. Our series showed a mean discrepancy between the measured and computed neck-shaft angle of 16° (0° to 52°) with the absolute range of error being three times this value. While most surgeons would have recognised grossly inaccurate computations for the neck-shaft angle, where the error for the proposed navigated position was within a small range such as 5° to 10° of varus to the true neck-shaft angle, the value may appear to be correct in the absence of accurate pre-operative templating.

Correct sizing of the femoral component is crucial for preservation of adequate bone stock and the avoidance of notching. Navigation tended to overestimate the correct implant size in both the clinical and laboratory setting. While the navigation system did not underscore any implant in the laboratory setting, it did in clinical use with the risk of producing notching of the femoral neck if the computed implant size was accepted. This risk would have been worsened with relative valgus positioning of the implant. Our results suggest that sizing should be estimated with a pre-operative plan and verified by a neck-gauge intraoperatively to ensure optimal selection of the implant. In our experience, the computed implant size and neck-shaft angle were often abandoned in favour of the pre-operative neck-shaft angle assessments.

Our study has not addressed implant translation or version. Although these are important factors in the optimal placement of a component, the planning software first positions the component using the superior head-neck junction point as a marker for implant depth and then aligns it according to the neck axis delineated by the centre of the femoral head and the selected point on the piriformis fossa. Deformity of the femoral head is common in patients undergoing hip resurfacing often with retroversion and anterosuperior deficiency. Initial intra-operative computation of femoral component alignment is performed by the computer algorithm placing the component in line with the centre of the femoral head and piriformis fossa point. Herein lies a source of error provided by the computer. Intra-operative planning of component position performed by the surgeon looks to verify and correct this initial alignment by using the anterior and posterior registration points and aligning the component properly between these boundaries.

Several investigators have examined the accuracy and precision of translation and version of a femoral component using imageless navigation. Using dry bone models with optimal CT-based planning, Cobb et al18 compared imageless navigation with conventional instruments and CT-based navigation for placement of the initial femoral guide-wire. All three methods showed similar levels of accuracy in AP translations with CT-based navigation providing superior precision (SD 1.6 mm) compared with a conventional jig (SD 3.4 mm, p < 0.003) and imageless navigation (SD 6.2 mm, p < 0.001). A similar finding was demonstrated for version of the guide-wire with comparable accuracy in the three methods, but imageless navigation showed the poorest precision (SD 9°) compared with CT-based navigation (SD 2°, p < 0.001) and conventional instrumentation (SD 5°, p = 0.015). By contrast, Resubal and Morgan8 showed that imageless navigation (SD 1.53°) was significantly more precise in determining version of the femoral component than a mechanical jig (SD 4.36°, p = 0.025) while demonstrating no difference in accuracy between the two methods. In a prospective, randomised study, Hart et al19 found that imageless navigation provided both significantly greater accuracy and precision in AP translation than a conventional jig. Numerous studies have shown increased accuracy and precision of imageless navigation compared with conventional jigs in coronal alignment of the implant6,8,19-24 with similar results to CT-based navigation.18 However, the contrasting results with respect to implant version8,18,19,23,24 indicates the inherent inconsistency in assessing this, and warrants further investigation of imageless navigation in this respect.

We acknowledge several limitations of our study. Errors in measurement during pre-operative planning on AP radiographs of the hip may occur if the films were obtained with the patient badly malpositioned or if there was deformed and obscured anatomy. It has been shown that rotational errors of the femur may contribute to erroneous measurement by radiography25-28 and this can result in discrepancies between the data measured pre-operatively and that registered by the navigation system. The cadaver study eliminated the effect of radiological malpositioning and may partially explain the smaller discrepancy between the measured and computed neck-shaft angle compared with that in
the clinical series. While the cadaver registration study did not exactly replicate the clinical setting for registration of the femur in hip resurfacing, it provided an optimal setting for evaluating the relative accuracy and reliability of the navigation process. Registration of denuded femora presents a best-case scenario in which complicating factors such as proximal femoral deformity, visibility of the registration point and preserved soft-tissue attachments were not present. Significant differences were found in the computed neck-shaft angle between surgeon registrations of the same femur in three of the ten femora indicating that despite an intended uniform registration technique, the process appeared to be sensitive to variations in its use.

In conclusion, there is strong evidence to support the use of imageless computer navigation for resurfacing arthroplasty. However, in order for it to be beneficial, the user must also be aware of its limitations. Computer navigation cannot correct for poorly selected patients or improperly implanted components. It is imperative that the surgeon selects appropriate patients and undertakes a thorough pre-operative templating before performing navigated hip resurfacing. Strict reliance on data obtained during intraoperative navigation may result in erroneous selection and positioning of the implant.

Supplementary material

A further opinion by Dr P. Bizot is available with the electronic version of this article on our website at www.bjs.org.uk

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References