Acetabular component navigation in lateral decubitus based on EOS imaging: A preliminary study of 13 cases

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Introduction: Acetabular component navigation classically requires palpation of the bone landmarks defining the anterior pelvic plane (APP) (anterior superior iliac spine [ASIS] and pubis), the recording of which is not very reliable when performed in lateral decubitus. The objectives of the current experimental study were: (1) to assess the clinical feasibility of NAVEOS navigation (based on EOS imaging) in lateral decubitus; and (2) to compare precision versus classical APP-based navigation (NAVAPP).

Hypothesis: Iliac plane navigation using EOS is as reliable as APP navigation.

Patients and methods: A continuous prospective series of 13 total hip replacements were implanted in lateral decubitus under APP-guided navigation (NAVAPP). Planning used preoperative EOS measurement. The ASIS, pubis and ipsilateral posterior superior iliac spine (PSIS) were located and exported to the simulator. Intra-operatively, NAVEOS landmarks (acetabular center, ASIS and PSIS on the operated side) were palpated. Postoperatively, cup inclination and anteversion with respect to the APP were measured on EOS imaging (SterEOS3D software). The SterEOS3D measurements were compared to those of the performed NAVAPP and simulated NAVEOS navigations.

Results: Three patients were excluded for technical reasons. In the remaining 10, inclination on NAVAPP and SterEOS3D differed by a median 4° (range, 0°–12°), and on NAVEOS versus SterEOS3D by 5° (range, 2°–10°); anteversion on NAVAPP and SterEOS3D differed by a median 4.5° (range, 0°–12°), and on NAVEOS versus SterEOS3D by 4° (range, 0°–14°).

Conclusion: Precision was comparable between NAVEOS and classical navigation. NAVEOS simplifies cup navigation in lateral decubitus on initial acquisition. These results require validation on a larger sample.

Level 4 study: Prospective case series.

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1. Introduction

Faulty acetabular component positioning may induce dislocation [1–5], early wear [6–8], excessive debris release [8–11], early loosening [12], squeaking [13] and iliosposa impingement [14]. Theoretically, navigation should reduce the rate of malpositioning outside of Lewinnek’s “safe zone” [15], which, although the subject of criticism, remains a reference concept [16,17]. Most currently used navigators do not require preoperative imaging, thus avoiding the issues of irradiation and cost incurred by the first, CT-based, systems in the 1990s [18,19].

Acetabular navigation without preoperative imaging classically requires locating the anterior pelvic plane (APP) by navigated palpation of the two anterior superior iliac spines (ASIS) and the pubis. In lateral decubitus, however, there is a risk of imprecision, mainly due to soft tissue [20–22], and of loss of operative field sterility during palpation of the pubis and of the contralateral ASIS, which is hard to access.

We developed a novel cup navigation technique in lateral decubitus, using preoperative EOS imaging [23], limiting initial palpation to two landmarks on the operated side: ASIS and PSIS (posterior superior iliac spine). These can be included in the operative field, to facilitate access. This “NAVEOS” navigation takes as reference the iliac field, defined by 3 points: acetabular center, ASIS and PSIS.

The study hypothesis was that NAVEOS simplifies acetabular navigation in lateral decubitus by palpating 2 rather than 3 points, both included within the operative field, and increases the precision of implant positioning, reducing the risk of error in landmark palpation. The study objectives were:

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• to assess the clinical feasibility of NAVEOS navigation and;
• to compare its precision versus classical APP-based navigation (“NAVAPP”).

2. Patients and method

2.1. Patients

Thirteen patients were included in a continuous prospective series. The inclusion criterion was indication for primary cementless hip replacement for primary osteoarthritis of the hip. Three surgeons used the same anterolateral Hardinge technique in lateral decubitus and cup navigation with the objective of positioning the cup in the safe zone defined by Lewinnek et al. [15].

Patients underwent preoperative EOS imaging. The landmarks required by NAVEOS navigation were marked on the images: APP landmarks (the 2 ASISs and the pubis), and the iliac plane landmarks on the operated side (ASIS, PSIS and acetabular center) (Figs. 1 and 2). The \( x \), \( y \), \( z \) coordinates on the EOS map were recorded under Excel™ (Microsoft, Redmond, USA) on a USB key. Each patient had an individual preoperative EOS Excel™ file.

2.2. Operative technique

The cup was implanted in lateral decubitus with pubic and sacral supports holding the pelvis. The ipsilateral ASIS and PSIS landmarks were manually palpated, skin-marked using a felt-tip pen, and included within the operative field (Fig. 3). The cup was a cementless model (Plasmacup, B. Braun, Germany) positioned using modified navigation software (modified Orthopilot V3.2, B. Braun, Germany). The APP landmarks (ASIS and pubis) were located in lateral decubitus through the operative field, as was the PSIS on the operated side. Navigation thereafter was standard. Inclination and anteversion were determined with respect to the APP, without reference to the PSIS. Target positioning was in Lewinnek’s “safe zone”: i.e., \( 40 \pm 10 \)° radiologic inclination and \( 15 \pm 10 \)° radiologic anteversion with respect to the APP, with optimal compromise with the acetabular bone contours. The final cup inclination and anteversion values with respect to the APP according to the NAVAPP data were recorded. NAVEOS navigation was then simulated, and cup orientation according to the NAVEOS software was recorded. Values with respect to the APP were calculated by mathematical transfer of the iliac to the anterior pelvic plane using the preoperative EOS data (Fig. 4).
2.3. Assessment

Postoperatively, repeat control EOS imaging was performed. The radiological anteversion and inclination of the cup implanted in the APP were measured by SterEOS3D software [24] following Murray [25], and represented the reference measurement (Fig. 5). Finally, there were 3-cup orientation measurements for each patient: the reference SterEOS3D measurement, the NAVAPP measurement and the NAVEOS simulation measurement.

The reference anteversion and inclination measurements were those of the postoperative SterEOS3D imaging. The target value was between 30° and 50° for inclination, and between 5° and 25° for anteversion. The NAVAPP and NAVEOS measurements were compared to the SterEOS3D reference.

2.4. Statistics

Results were presented as box-plots of median, quartile and range to visualize the distributions. Anteversion and inclination values were compared using Friedman non-parametric tests.

3. Results

Three of the 13 patients initially included were subsequently excluded for technical reasons and learning-curve issues (software or instrumentation error) interrupting navigation before the orientation values could be determined. The complete protocol was performed on 10 patients: 7 females, 3 males. Mean age was 64 years (range, 52–77 years) and mean body-mass index 24 (range, 20–29).

Table 1 presents radiological results with respect to the APP following Murray [25]. The NAVAPP inclination value deviated by a median 4° from the reference value (range, 0–12°; 1st quartile [Q1]=1°, 3rd quartile [Q3]=9.75°) and the NAVEOS value by 5° (range, 2–10°; Q1=4°, Q3=7°) (P=0.20). For anteversion median deviation was 4.5° for NAVAPP (range, 0–12°; Q1=2.25°, Q3=8.5°) and 4° for NAVEOS (range, 0–14°; Q1=2.25°, Q3=8.75°) (P=0.74). These deviations were non-significant on Friedman test (Fig. 6).

4. Discussion

Navigation has proved contributive to acetabular implant positioning in hip replacement [16,17]. It has, however, shown limitations in terms of precision [20–22] and also for implementation in lateral decubitus. EOS-based iliac plane navigation has never been clinically assessed, but could simplify the procedure in lateral decubitus by requiring initial acquisition with only 2 easily located palpation points included within the operative field: ASIS and PSIS. The NAVEOS landmarks were easily visualized on the preoperative EOS view, and the data-files were valid and implementable.

<table>
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<tr>
<th>Inclination</th>
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on the Orthopilot™ “NAVEOS test” mode. The present preliminary study tested implementation of the NAVEOS software and demonstrated its clinical feasibility and precision, finding no difference in precision between NAVAPP and NAVEOS.

The study involved several limitations:

- there is a learning-curve for the software and guide; 3 patients were excluded due to navigation or instrumentation issues, leading to termination of the procedure before positioning could be achieved;
- the sample was small (10 cases), precluding sufficient statistical power. However, NAVEOS navigation was simulated a-posteriori in a mathematical transfer limiting the risk of imprecision. The differences between values were thus due to error in preoperative EOS landmarking or imprecise bone landmark palpation;
- acetabular centering tends to be a source of error, by assimilating the acetabulum to a sphere; but this is true for both NAVEOS and NAVAPP navigation;
- three surgeons were involved; but all were experienced with the navigation software, and had the same inclination and anteverision target values;
- positioning the cup within Lewinnek’s safe zone with respect to the APP, of which the dynamic changes are known, is also open to criticism [26,27]; in the current absence of consensus as to optimal acetabular component positioning, however, this choice seems justifiable.

The objective of NAVEOS navigation is not to achieve the “right position”, but to place the cup as precisely as possible according to the preoperative EOS plan, with the APP simply as reference plane. The cup could just as well be positioned directly with reference to the iliac plane, by defining values for new orientation angles. We used the APP, which has been widely studied, being easy to locate radiologically, so that optimal positioning in this plane has been well assessed, the main problem being that of access in lateral decubitus.

The current results showed no inferiority in precision with NAVEOS compared to NAVAPP; deviations were not significantly different with respect to the SterEOS3D reference. Both methods may deviate by up to 10° from reference values. Finally, NAVEOS navigation seems neither more nor less precise than NAVAPP. The degree of deviation may partly be due to a 3° variation in the measurement of anteverision on SterEOS3D [24]. In our up-coming prospective study, reference measurements will be taken on CT scan.

The number of cups implanted outside of the safe zone using a free-hand technique is very large. DiGioia et al. [28] reported 78% unacceptable alignment using a mechanical guide. Hassan et al. [29] reported 21 out of 50 cups outside the safe zone and Saxler et al. [30] found 78 out of 105. Other studies confirm these worrying findings [31,32] and stress the fact that free-hand acetabular implantation is unreliable. Beckmann et al. [16] performed a systematic review of
the literature on navigation-assistance, testing the hypothesis that cup positioning is more precise with navigation than with a free-hand technique [16]; only 5 of the 363 publications retrieved were of sufficient level of evidence; the difference in rate of safe zone positioning was significantly in favor of navigation. In a prospective randomized controlled study of 60 patients, Parratte et al. [17] positioned the cup outside the safe zone in 57% of cases with a free-hand technique, versus 20% with navigation [17].

Navigation based on APP palpation is difficult in lateral decubitus. To get around this, surgery can be performed with supine patient positioning; alternatively, as recommended by certain authors, the APP may be acquired in supine position and the patient then “flipped” into lateral decubitus for surgery [33]. Other navigation techniques do not use the APP at all, but rather the implant’s range-of-motion cone [34] or the peri-acetabular plane [35]; nevertheless, the APP is still the reference plane most widely used at the present time, having the advantage of remaining constant for cup orientation regardless of the patient’s position (seated, standing or supine) [36].

Another alternative is to use an intermediate plane, such as the transverse pelvic plane [37], or the iliac plane, as assessed in the present study, to obtain the APP. The advantage of the iliac plane navigation we propose here is that palpation requires only 2 easily accessible landmarks; but it does require preoperative EOS imaging. Further ergonomic efforts are needed. However, the present preliminary results are sufficiently encouraging, in terms of both feasibility and precision, for a prospective comparative clinical study to be performed and for investigation to continue.

5. Conclusion

Acetabular cup navigation in the iliac plane, based on preoperative EOS imaging, is an alternative to navigation in the APP without preoperative imaging. It could simplify initial acquisition in lateral decubitus without upsetting surgical habits, as the APP remains the reference plane for NAVEOS navigation, the iliac plane being merely intermediate. The present study demonstrated clinical feasibility. Precision was comparable to that with classical navigation. These results now require validation in a larger patient sample.

Disclosure of interest

Dominique Chauvaux declares that he has no conflicts of interest concerning this article, but is an occasional consultant for I-CERAM. The other authors declare that they have no conflicts of interest concerning this article.

References