Orientation of the acetabular component

A COMPARISON OF FIVE NAVIGATION SYSTEMS WITH CONVENTIONAL SURGICAL TECHNIQUE

M. Honl,
K. Schwieger,
M. Salineros,
J. Jacobs,
M. Morlock,
M. Wimmer

*From Rush
University Medical
Centre, Chicago,
Illinois, USA*

■ M. Honl, Dr. med, Dr.
Ing.habil, Professor,
Orthopaedic Surgeon
Department of Orthopaedic
Surgery, LKH Klagenfurt, A-
9020 Klagenfurt, St. Veiter
Strasse 47, Carinthia, Austria.

■ K. Schwieger, Dr. Ing, Group
Leader
AO Research Institute,
Clavadelerstrasse 8, CH-7270
Davos Platz, Switzerland.

■ M. Salineros, MD,
Orthopaedic Surgeon
■ J. Jacobs, MD, Professor,
Orthopaedic Surgeon
■ M. Wimmer, Dr. Ing,
Professor, Director of Tribology
Rush University Medical
Center, 1653 W. Congress
Parkway, AcFac 726b, Chicago,
Illinois 60612, USA.

■ M. Morlock, Dr. habil, PhD,
Professor, Director of
Biomechanics
Biomechanics Section
TU Hamburg-Harburg,
Denickestrasse 15, D-21073,
Hamburg, Germany.

Correspondence should be sent
to Professor M. Honl; e-mail:
matthias.honl@lkh-klu.at

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We compared the orientation of the acetabular component obtained by a conventional manual technique with that using five different navigation systems.

Three surgeons carried out five implantations of an acetabular component with each navigation system, as well as manually, using an anatomical model. The orientation of the acetabular component, including inclination and anteversion, and its position was determined using a co-ordinate measuring machine.

The variation of the orientation of the acetabular component was higher in the conventional group compared with the navigated group. One experienced surgeon took significantly less time for the procedure. However, his placement of the component was no better than that of the less experienced surgeons. Significantly better inclination and anteversion ($p < 0.001$ for both) were obtained using navigation. These parameters were not significantly different between the surgeons when using the conventional technique ($p = 0.966$).

The use of computer navigation helps a surgeon to orientate the acetabular component with less variation regarding inclination and anteversion.

Correct orientation of the acetabular component including inclination and anteversion, and the exact positioning of its centre are important factors for the outcome of total hip replacement (THR). Dislocation,¹⁻⁵ increased wear⁴⁻⁶ and impingement⁷⁻¹⁰ can be caused by misalignment.

Computer-assisted surgery is increasingly being used to optimise the positioning of components.¹¹⁻¹⁵ Minimally-invasive surgery may allow a restricted view, and calls for intra-operative imaging,¹⁶⁻¹⁹ or computer-assisted surgery.²⁰⁻²²

Active systems (robotic) were popular in Europe for reaming the femur in the mid-1990s but the early clinical results did not justify their widespread use.²³ Passive navigation systems provide the surgeon with information about the position of instruments or components within a reference system. The system allows the surgeon to work within a virtual anatomy.²⁴⁻²⁷

There are two different types of navigation system, image-based and image-free. Image-based systems require CT images to be obtained pre-operatively²⁸ which are then registered with the three-dimensional (3D) co-ordinates of the patient and the virtual image. Fluoroscopic images obtained intra-operatively can

also be used.²⁷ Image-free systems are based on kinematic data or point-clouds that are acquired intra-operatively.^{24,25,29,30} Computer-assisted navigation systems using the point-cloud points make a 3D reconstruction image that can be explored on a computer screen.

There are few studies that show an improvement in placement of the acetabular component using computer-assisted surgery, and these have small numbers of patients or samples.^{27,29,31} It is not known whether the use of computer-assisted surgery improves accuracy when used by different surgeons or if image-based³¹⁻³⁷ or image-free systems^{24,25,38-41} yield different results.

The aim of our study was to compare the orientation and position of acetabular components using different computer-assisted surgery systems, and the conventional surgical technique.

Materials and Methods

We used five different systems of computer-assisted surgery: Navitrack image-free (Zimmer, Warsaw, Indiana), Navitrack image-based (Zimmer), Orthopilot (image-free; Aesculap, Tuttlingen, Germany), VectorVision (image-based; Brainlab, Munich, Germany) and Surgetics-Station (image-free; Praxim-Medivision, Bern, Switzerland). We performed CT scans of

Fig. 1

Graph showing the procedure duration vs surgeon and navigation-group.

the pelvis of a female cadaver, according to the manufacturer's specifications. A rectangular block, including the left acetabulum, was removed from the pelvis. The whole block was then moulded in silicone (Elastosil, Wacker-Chemie GmbH, Bughausen, Germany) and 90 acetabular components of polyurethane foam (Bayer AG, Leverkusen, Germany) were made. The advantage of using these acetabula was that there was no variation in the anatomical features or material properties, as would have occurred with cadaver specimens.

The acetabula were placed in a dummy that was similar to a real patient in height and volume, to match the proportions and the position on an operative table. To make the model more realistic a femur, after resection of the head, was inserted into the thigh and soft foam was used to represent the capsule. The dummy was draped and positioned supine on an operating table. A new model of the acetabulum was placed in the pelvis and the dummy repositioned before each implantation. The model of the acetabulum was a tight press-fit in the pelvis and therefore the position and orientation of the model was the same for each implantation.

Three surgeons with no previous experience of computer-assisted surgery undertook the surgery following training by a company representative from each of the manufacturers. Surgeon 1 was a resident in the second year of training who had previously implanted ten hips; surgeon 2 was a consultant who had performed 70 THRs and surgeon 3 was a consultant who had performed 480 THRs. The authors did not participate in the surgery.

An angle of inclination of 30° with 10° of anteversion was chosen for each acetabulum. The company representa-

tives performed the calibration, point acquisition and registration for each acetabulum, in order to eliminate inappropriate use of the systems. The different systems of computer-assisted surgery used different acetabular components and therefore, four different spherical press-fit components had to be used.

We used Allofit (Zimmer), Plasma-Cup (Aesculap), Duraloc (DePuy, Warsaw, Indiana) and Kaputliner (ESKA, Lübeck, Germany) components, all of 56 mm in diameter. None of the surgeons had implanted these components previously, but all used spherical press-fit prostheses in their routine clinical practice. Each surgeon implanted five system-specific components using a conventional technique, and five components using computer-assisted surgery. The operations were carried out in a random order decided by a random number generator (SPSS 11.5, Munich, Germany). The surgeons had full access to the navigational tools until the component had been positioned, but were prevented from using the orientation-confirmation tool within the programme. Each surgeon was asked to estimate the orientation that had been achieved. The time taken for the surgery was recorded.

The acetabular model was mounted on a co-ordinate measuring machine (Mitutoyo, Neuss, Germany).¹² The angles of inclination and anteversion were measured with an accuracy of SD 0.5°. The craniocaudal (x), the medio-lateral (y) and the anteroposterior (z) positions were determined with an accuracy of SD 0.1 mm. These co-ordinates were used to determine the length of the malposition vector:

$$\sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} = \text{malposition vector.}$$

Statistical analysis. Analysis of variance (ANOVA) was calculated using SPSS version 11.5 (SPSS, Munich, Germany).

Fig. 2

Graph showing the angle of inclination vs the surgeon and navigation group (30° was planned).

The independent variables were the surgeons, and the different methods of implantation (the five navigation systems, and the conventional method), while the dependent variables were the time taken, inclination, anteversion and the difference between the planned angles and the angles that were achieved. For the difference between the planned location of the centres of the acetabular component and that achieved, a Scheffe test⁴² was performed as a *post-hoc* test when applicable. Pearson correlation coefficients (r_p) were calculated for the comparison of the surgeons' estimate of the position of the acetabular component and the measured positions.

Results

Surgeon 3 was significantly faster at performing the surgery ($p < 0.001$) for the conventional method, image-free and image-based (Fig. 1). The factor 'surgeon' did not significantly influence inclination ($p = 0.537$, Fig. 2) or anteversion ($p = 0.336$, Fig. 3). The variable 'implantation method' was significant for inclination ($p = 0.001$) and anteversion ($p = 0.001$).

The mean procedure duration for the last sample of a series for all surgeons was 6.44 mins (SD 1.56) in the navigated groups and 3.34 mins (SD 1.15) in the conventional group.

In the conventional group surgeon 2 achieved a mean angle of inclination (31°, SD 6.9) that was quite well matched with the selected angle. Surgeon 1 implanted the components with too little inclination and surgeon 3 with

too great an inclination (Fig. 2). There was more variance of the angle of inclination within the conventional group compared with the computer-assisted surgery groups.

Within the computer-assisted surgery groups, the smallest errors in inclination were observed in the Surgetics-Station system. In comparison, the image-based Navitrack had lower angles of inclination ($p = 0.53$) and the Vector-Vision system, significantly higher angles ($p = 0.042$, Fig. 2).

In the conventional group of implantations all the surgeons had lower angles of anteversion than those planned (Fig. 3). Surgeon 1 had the highest variance. In the computer-assisted surgery groups the smallest errors were observed using the Orthopilot system. Compared with this system, the VectorVision had lower angles of anteversion ($p = 0.043$).

The correlation coefficients between the angles estimated by the surgeons and the measured angles were more accurate for inclination ($r_p = 0.636$, $p < 0.001$) than for anteversion ($r_p = 0.160$, $p = 0.132$).

The position of the component, as indicated by the length of the malposition vector between the planned and the actual location of the centre, was not significantly different for all the surgeons in the conventional group ($p = 0.966$). There were statistically-significant differences in the computer-assisted surgery groups. The image-free Navitrack group had smaller errors when compared with the conventional, and the other computer-assisted surgery systems ($p = 0.001$). The image-based Navitrack and the VectorVision groups had higher errors ($p \leq 0.001$, Fig. 4).

Fig. 3

Graph showing the angle of anteversion vs the surgeon and navigation group (10° was planned).

Fig. 4

Graph showing the malposition of the component (lengths of the vector between planned and reamed centre) vs navigation group.

Discussion

Dislocation of a total hip replacement may be caused by inaccurate positioning of the acetabular component.^{1,3-5} If the component is implanted within the safe zone, for both inclination and anteversion, the rate of dislocation can be reduced from 5% to 1%.⁵ The safe zone has been revised by Yoshimine⁴³ to allow for range of movement, impingement and wear. Yoshimine regards anteversion as the main factor.⁴³ Our study shows that the surgeons' estimate of the angle of anteversion did not correlate well with the meas-

ured angles. The variation was high and many components were placed outside the safe zone.

The time taken for the surgery was significantly influenced by the surgeon, but surgeon 3, who was the most experienced and quickest, did not produce the best results. This is in contrast to the common criticism of computer-assisted surgery that it may only be required by inexperienced surgeons.^{44,45}

The differences in orientation of the acetabular component between the computer-assisted surgery systems were not, for the most part, significant but the angle of inclination achieved with the VectorVision system was smaller when compared with the rest. This could be a systematic problem related to having a different algorithm for pelvic orientation. The image-based Navitrack had better results compared with the conventional group. The other computer-assisted surgery systems demonstrated greater malposition than the conventional group. The mean error was 6.39 mm (SD 2.44), which is not clinically relevant. This could have been caused by the surgeon watching the monitor instead of the surgical field. The significantly lower malposition in the image-free group indicates that pre-operative CT may not be required.

After the initial learning curve the extra time taken for computer-assisted surgery was approximately three minutes when compared with the conventional technique. This does not increase morbidity or the cost of surgery.

The accuracy of placement of the acetabular component in the computer-assisted surgery groups was achieved in a technically ideal situation. During live surgery, errors caused by faulty referencing and the possibility of shut-down of the system have to be considered.

We chose to use a number of different systems of computer-assisted surgery in order to be able to draw conclusions about navigation in general, rather than one specific system.²⁵ The object of our study was not to promote one system at the expense of others, but we could not entirely eliminate bias.

We used a simplified model but there was no indication that this made the surgery easier, or more difficult.

The use of computer navigation allows the surgeon to place the acetabular component with less variation of inclination and anteversion, although this does not necessarily reflect the level of experience of the surgeon.

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