Computer navigation of the acetabular component
A CADAVER RELIABILITY STUDY

J. M. F. Spencer, R. E. Day, K. E. Sloan, R. J. Beaver
From the Royal Perth Hospital, Western Australia

Our aim was to assess the intra- and inter-observer reliability in the establishment of the anterior pelvic plane used in imageless computer-assisted navigation. From this we determined the subsequent effects on version and inclination of the acetabular component.

A cadaver model was developed with a specifically-designed rod which held the component tracker at a fixed orientation to the pelvis, leaving the anterior pelvic plane as the only variable. Eight surgeons determined the anterior pelvic plane by palpating and registering the bony landmarks as reference points. The exact anterior pelvic plane was then established by using anatomically-placed bone screws as reference points.

The difference between the surgeons was found to be highly significant (p < 0.001). The variation was significantly larger for anteversion (SD 9.6˚) than for inclination (SD 6.3˚). The present method for registering pelvic landmarks shows significant inaccuracy, which highlights the need for improved methods of registration before this technique is considered to be safe.

Accurate alignment of the acetabular component in total hip replacement is extremely important if impingement, dislocation and the rates of polyethylene wear are to be reduced.1 Lewinnek et al2 recommended an inclination of 40˚ (SD 10˚) and anteversion of 15˚ (SD 10˚). Most surgeons aim for 45˚ of inclination and 20˚ of anteversion using mechanical devices provided by the manufacturer of the implant. These angles are determined relative to the anterior pelvic plane and all these devices assume a fixed pelvic position at 90˚ to the floor. Any pelvic malalignment can therefore lead to malposition of the component if mechanical jigs are used. McCollum and Gray3 reported that pelvic alignment in the lateral position can be extremely unreliable. These problems have lead to an increasing interest in navigation systems for orientation of the acetabular component. They can be image-based, using CT or fluoroscopy, or image-free. All require the definition of the anterior pelvic plane and all subsequent measurements are based on this. For image-free systems the anterior pelvic plane is based on percutaneous registration of the anatomical landmarks, the anterior superior iliac spines and pubic symphysis.

Our hypothesis was that there is significant intra- and interobserver error in recording anteversion and inclination of the acetabular component using this model.

Materials and Methods
The anterior pelvic plane is defined as the plane formed between a line joining both anterior superior iliac spines and the pubic symphysis. The 3D reference co-ordinate system is used to place the component (X, Y and Z axes). The X-axis is the transverse axis, defined as a line from the right to left anterior superior iliac spines. The Y-axis is perpendicular to the X-axis in the plane of the anterior pelvic plane. The Z-axis is perpendicular to the anterior pelvic plane.

We used the Stryker image-free hip navigation system (version 1.1; Stryker, Perth, Western Australia). We aimed to create a cadaver model in which the anterior pelvic plane was the only variable. We used a male cadaver. The acetabulum was exposed using a standard anterolateral approach. The orientation of the pelvic plane was determined by the registration of the landmarks made by the surgeons in each trial. It therefore varied each time it was re-registered. A hole was drilled in the base of the acetabulum at an approximate angle of 45˚ of inclination and 20˚ of anteversion. A specially-designed plastic liner was cemented into this hole flush with the base of the acetabulum and left in situ for the duration of the study. A removable metal rod was manufactured which could be placed within the liner and which allowed the computer tracker to be fixed to it.
The cadaver was prepared and draped as for a total hip replacement and placed in the lateral position. It was then rolled backwards by 30° to ease the identification of the landmarks while maintaining theoretical sterility. An anchoring pin was inserted into the pelvic brim, to which the tracker was attached as is the routine procedure for hip navigation.

We recruited eight surgeons into the study (four consultants and four senior registrars). All were familiar with conventional hip replacement and six were familiar with the use of computer navigation for knee replacement, but not for total hip replacement. Each was asked to identify and register the landmarks of the anterior pelvic plane with the standard pointer. They repeated the process ten times with an enforced two-minute break between trials in order to mimic a new patient at each attempt. All were given two practice attempts before the commencement of the trial. They were not given feedback as to how accurate an anterior pelvic plane they had mapped.

After each trial the version and inclination of the rod were recorded. At the end of the study the exact anatomical landmarks were dissected out and small bone screws were inserted flush with the bone. The correct anterior pelvic plane was then re-mapped ten times by the main investigator only (JMFS) using the screws as landmarks. The version and inclination of the rod were then recorded.

Finally, a multi-slice CT scan of the pelvis with 0.5 mm cuts was obtained to verify the version and inclination of the rod and to compare these with the navigation system. Statistical analysis. We used two one-way analysis of variance (ANOVA) tests to determine differences between the ten trials (one-way repeated measures ANOVA) and between the eight surgeons (one-way random effects ANOVA). A p value < 0.05 was considered to be statistically significant. An estimate of intra- and interobserver error was calculated using the latter analysis by separating the variance components contained in the model. The errors were expressed as 95% confidence intervals (CI).

Results

Digitisation of the anterior pelvic plane, using the screws as markers confirmed the rod to be at 55° of inclination and at 20.6° of anteversion. The CT scan determined the rod to be inclined at 55° and to be anteverted by 19° relative to the anterior pelvic plane. The fact that the rod was malplaced was not relevant to the surgeons during the mapping process as they were not aware of the exact orientation of the rod until the end of the trial. The spread of the points digitised by the surgeons relative to the anterior pelvic plane are shown in Figure 2. The variation between the surgeons and between the trials for each surgeon for anteversion and inclination are shown in Figures 3 and 4. All the results were compared with the position in which the rod was fixed.

Our findings showed that the difference between the surgeons was significant with SD 5.9° (95% CI) for inclination...
and SD 9.6˚ (95% CI) for anteversion (p < 0.001). The intraobserver error (SD 4.3˚ for inclination and SD 6.3˚ for anteversion) was not significant.

Discussion

The reason for using any device when implanting the acetabular component, whether computer-aided, jig-based or manual, is to maximise the likelihood of accurate orientation. Precise positioning minimises the risk of impingement, dislocation and wear. Computer navigation is a relatively new tool designed to increase the accuracy of the implantation of components. Improved alignment of components has been shown in total knee replacement surgery and, more recently, in hip replacement surgery using this technique. However, computer navigation will only lead to accurate implantation of a component if the initial information fed into the computer is accurate. During total knee replacement most of the landmarks required by the software can be exposed directly or palpated easily, thereby minimising the chances of error during the mapping process. However, the pelvic landmarks are mapped through tissue of variable thickness which increases the likelihood of inaccuracy. In a recently published model for estimating the error of alignment of the components in total hip replacement, it was shown that a small error in marking the bony landmarks of the anterior pelvic plane has a significant effect on the final orientation of the component.

Our study has shown that the identification and registration of the pelvic landmarks are subject to significant variation. The subsequent variation in the anterior pelvic plane produced errors in both the inclination and anteversion of the acetabular axis. The intraobserver error is larger for anteversion (SD 6.3˚) than for inclination (SD 4.3˚) and the interobserver error accentuates this, producing a significantly larger variation for anteversion (SD 9.6˚) than inclination (SD 5.9˚). We feel that this confirms that our original hypotheses were correct. Final placement of the acetabular component may introduce additional error. However, since this is done with direct feedback from the navigation system, we feel that it is likely to be small.

The study of DiGioia et al. in 2002 found that 78% of acetabular components inserted by conventional means were in an unacceptable position. A prospective, randomised study comparing implantation of the acetabular component using the freehand technique with CT-based and image-free navigation found that imageless navigation...
was as reliable as CT-based navigation in the positioning of the acetabular component, and that both were significantly better than the conventional freehand method. Our study has shown that although a significant amount of variability was found during mapping of the anterior pelvic plane, only two of 80 (2.5%) measurements would have placed an acetabular component outside the safe zone as described by Lewinnek et al. Therefore image-free computer navigation of the acetabular component may be a promising technique which minimises the frequency of extreme placement of the component. However, awareness of the potential inaccuracies of this method are likely to result in more careful mapping of the landmarks and therefore increase the reliability of the procedure.

Our study was performed on a cadaver with stiffer, less compliant tissue than that of a live patient, making the landmarks more difficult to palpate. The cadaver was thin, improving the ease of palpation. Although our study has not specifically investigated it, the degree of error in obese patients is likely to be much greater because landmarks may be many centimetres below the skin, obscured by tissue and hard to palpate. This may result in a highly inaccurate anterior pelvic plane with an associated highly inaccurate placement of the component.

We also acknowledge that we performed our mapping in the lateral position and that palpation of the landmarks is likely to be easier in the supine position. Further work is required to clarify if this would significantly improve the reliability of the method.

In conclusion, we have shown that there is a potentially significant degree of variability and error in mapping of the anterior pelvic plane using computer navigation to position the acetabular component. Although our results relate only to one image-free system, these errors will be present in all navigation systems which rely on percutaneous palpation to establish the anterior pelvic plane. Interobserver variability is greater than intraobserver variability and the error is greatest for anteversion (SD 9.6°). If inaccurate data is initially put into the computer (by inaccurate mapping of the anterior pelvic plane) the final position of the component as determined by the navigation system will also be inaccurate. We feel that potential users need to be aware of this in order to avoid being misled significantly by these systems.

We wish to acknowledge the assistance of the Stryker Corporation (Perth, Western Australia) in this work. They provided the cadaver, the imageless hip navigation equipment as well as technical back-up for the project.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References