Navigated non-image-based positioning of the acetabulum during total hip replacement

Jean-Yves Jenny · Cyril Boeri · Jean-Claude Dosch ·
Marius Uscatu · Eugen Ciobanu

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Abstract We tested the hypothesis that the non-image-based navigation system used in our department was able to measure accurately the 3D positioning of the acetabular cup of a total hip replacement (THR) and to increase the accuracy of its implantation during THR. We studied 50 consecutive navigated implantations of a THR and compared the intra-operative measurement of the cup by the navigation system to the post-operative measurement by computed tomography (CT) scan. The mean difference between the navigated and CT scan measurements for cup inclination was 2°. The mean difference between the navigated and CT-scan measurements for cup flexion was 4°. These differences were significant but considered to be clinically irrelevant in most cases. A total of 73% of the cases were within the safe zone defined prior to the study. The non-image-based system used allows a precise orientation of the cup during THR.

Résumé Le but de notre étude est de mettre en évidence la possibilité de positionner de façon précise, dans les trois plans de l'espace, la cupule d'une prothèse totale de hanche et d'améliorer ainsi son implantation. Nous avons étudié 50 prothèses consécutives naviguées en comparant la mesure per opératoire de la cupule par le système de navigation et la mesure post opératoire par scanner. La différence entre les mesures faites par navigation et les mesures par scanner ne montre au niveau de l'inclinaison de la cupule qu'une différence de 2° et pour la flexion de 4°. Ces différences sont significatives mais n'ont aucune conséquence clinique

dans la plupart des cas. 73% des cupules étaient dans la zone de sécurité que nous avons définie avant de mettre en route cette étude. En conclusion, le système de navigation sans image permet une orientation précise de la cupule lors d'une prothèse totale de hanche.

Introduction

The precise positioning of the acetabular cup is an important feature during total hip replacement (THR). It has a significant influence on both short-term (luxation, impingement) and long-term (wear, loosening) outcomes [1, 7, 21]. It has been demonstrated that the conventional, manual positioning is less than optimal [4]. A navigation system might allow increasing the accuracy of this positioning. We tested the hypothesis that the non-image-based navigation system used in our department was able to measure accurately the 3D positioning of the acetabular cup of a THR and to increase the accuracy of its implantation during THR.

Materials and methods

We studied 50 consecutive navigated implantations of a THR. The study was approved by our local institutional board and all patients gave written informed consent.

We used on a routine basis the OrthoPilot® system (Aesculap, Tuttlingen, FRG) for THR. The basis of the system and software has already been validated for total [19] and unicompartmental [9] knee replacement. The knee system has been adapted for THR. This system is non-image-based, as it relies only on intra-operatively collected anatomical and kinematic data, without any pre-operative

J.-Y. Jenny (✉) · C. Boeri · J.-C. Dosch · M. Uscatu · E. Ciobanu
Centre de Chirurgie Orthopédique et de la Main,
Hôpitaux Universitaires de Strasbourg,
10 Avenue Baumann,
67400 Illkirch-Graffenstaden, France
e-mail: jean-yves.jenny@chru-strasbourg.fr

additional imaging. The operative technique has been described elsewhere [13]. Briefly, the patient lay supine on the operating table. One infrared localiser was fixed with a percutaneous screw to the anterior iliac crest on the side to be operated. The reference frame was chosen to be the anterior pelvic plane [14]. The surgeon palpated three anatomical landmarks with a navigated stylus: both antero-superior iliac spines and pubic symphysis. The 3D positions of the pelvic localiser and of the stylus were recorded by the infrared Polaris® camera (Northern Digital, Canada). The 3D pelvic orientation was taken as the reference position. After the antero-lateral approach, neck osteotomy and head removal, a navigated trial cup was inserted prior to reaming to define the initial centre of the acetabulum and the medial wall of the acetabulum was palpated with the navigated stylus.

Navigated reamers were used to prepare the acetabulum. A navigated holder allowed the positioning of the trial cup with the desired orientation (Fig. 1). The same navigated holder allowed positioning the final implant during cementation. The desired orientation of the cup was chosen following Lewinnek's proposal of a safe zone [14]: $45^\circ \pm 10^\circ$ of inclination and $15^\circ \pm 10^\circ$ of flexion. The final orientation of the cup after cement polymerisation was registered.

A post-operative computed tomography (CT) scan was performed before discharge. The three anatomical landmarks were identified on the 3D reconstructions and the Lewinnek plane was defined as the reference plane. The position of the acetabular cup was defined along the larger diameter of the wire ring on the appropriate reconstructed slice. The orientation of the cup in comparison to the Lewinnek plane was recorded in the three directions (inclination, rotation and flexion) but only inclination and flexion were analysed, as they represent the actual intra-operative criteria which are analysed by the surgeon. The inclination and flexion angle measured on post-operative

CT were compared to the intra-operative measurement with a paired *t*-test and a correlation test at a 0.05 level of significance. The number of "outliers" (measurements out of the safe zone of Lewinnek) was also recorded for each individual direction and as a whole.

Results

Forty-eight out of the 50 cases have been analysed; for two cases, it was not possible to detect the cup positioning accurately on the post-operative CT scan.

Figure 2 shows the results of the cup inclination. The mean navigated inclination was $42^\circ \pm 4^\circ$ (range, 35° to 49°); the mean CT inclination was $44^\circ \pm 5^\circ$ (range, 30° to 57°). The mean paired difference was $-2^\circ \pm 4^\circ$ (range, -12° to 9°); this difference was significant ($p=0.003$). There was a significant correlation between the navigated inclination and the CT inclination ($p<0.001$). Forty-one of the 48 cases (41/48, 85%) showed a difference of less than 5° between the two measurements. Forty-two of the 48 cases (42/48, 87%) were within the safe zone of CT measurement.

Figure 3 shows the results of the cup flexion. The mean navigated flexion was $15^\circ \pm 3^\circ$ (range, 6° to 22°); the mean CT inclination was $19^\circ \pm 7^\circ$ (range, 2° to 32°). The mean paired difference was $-4^\circ \pm 8^\circ$ (range, -25° to 19°); this difference was significant ($p=0.003$). There was no significant correlation between the navigated flexion and the CT flexion ($p=0.54$). Twenty-eight of the 48 cases (28/48, 58%) showed a difference of less than 5° between the two measurements. Thirty-eight of the 48 cases (38/48, 79%) were within the safe zone of CT measurement.

Fig. 1 Intra-operative screenshot: trial cup orientation

Fig. 2 Results of the cup inclination ($^\circ$). The safe zone is the shaded area

Fig. 3 Results of the cup flexion (°). The safe zone is the shaded area

When combining the two measurements, 35/48 cases (73%) were within the safe zone of CT measurement for the global orientation of the cup (Fig. 4).

Discussion

The positioning of the cup of a THR is considered to be critical for the short- and long-term results of the procedure [21]. There is no general agreement regarding the ideal reference to measure cup orientation. The most accepted reference was defined by Lewinnek et al. [14] as the anterior pelvic plane. It is the plane containing the three following points: both antero-superior iliac spines and the pubic symphysis.

Fig. 4 Results of the cup inclination together with the cup flexion (°). The safe zone is the shaded area

The post-operative cup positioning can be measured on post-operative X-rays or CT scan. The accuracy of X-rays is questionable, because slight variations in the patient's positioning can result in significant variation of the measurements [22]. Furthermore, measurement of the cup flexion is only indirect and might be less than accurate [15]. CT scan is well accepted as the gold standard for this purpose [11].

Conventional techniques involve manual orientation of the cup according to anatomical landmarks and/or pelvis positioning. However, it has been demonstrated that there are significant pelvic movements during THR [4] and that the pelvic position could not be considered as a reliable intra-operative reference for cup orientation. Digioia et al. observed that 78% of cups were oriented outside the safe zone when they controlled the positioning of the cup intra-operatively with a CT-based navigation system [4]. These results have been confirmed by other authors, who reported similar rates of outliers: 50% for Kalteis et al. [10] and 45% for Wines and McNicol [23]. There is an inherent inaccuracy of the conventional techniques and navigation systems might address this issue.

Most navigation systems for THR rely on a matching between the pre-operative CT scan imaging and the intra-operative registration of points or surfaces [4, 6] or intra-operative fluoroscopy [5]. However, CT scanning is not recognised as a routine pre-operative investigation and these techniques induce additional radiation exposure for the patient and additional cost for the health care system in comparison to the conventional technique of THR. Non-image-based systems rely on fully intra-operative registered data, with no additional pre-operative costs. These systems proved to be as reliable as CT-based systems, both in experimental [8] and clinical [12] studies.

To our knowledge, only two navigation systems have been validated in clinical use by a comparison between intra-operative navigated measurements and post-operative CT scan measurements [12, 17]. All other studies only compared the rate of cups implanted in the desired orientation on post-operative CT scans between a navigated and a conventionally operated group of patients.

The OrthoPilot® system (Aesculap, Tuttlingen, FRG) relies on an intra-operative anatomical registration of the anterior pelvic plane for the definition of the pelvic orientation. A navigation system can only be effective if the reference frame can be defined in a confident way. The Lewinnek plane has been validated as a reliable reference by Mayr et al. [16], who demonstrated that pelvic orientation was stable with regard to the supine and standing positions; furthermore, these results were independent of sex, level of arthrosis or status after the implantation of a THR. Cutaneous palpation of the pelvic anatomical landmarks might be inaccurate because of the

smooth shape of the landmarks and the distance between the skin surface and the real bone contour [18, 20]. Richolt et al. [18] demonstrated that a 10° precision was necessary for clinical significance. The technique used in this study is still robust. Theoretical calculation showed that a 10-mm error in the location of the top of the antero-superior iliac spines induces only a 3° error in inclination and a 4° error in flexion [24]. Furthermore, we demonstrated in a clinical study that the intra-operative palpation of this plane was accurate and reproducible. Intra-operative sonography might address this issue [18].

There was, in our study, a significant difference between paired intra-operative navigated and post-operative CT measurements. The variation between intra-operative navigated and post-operative CT measurements can be explained by other reasons than the potential inaccuracy of reference plane palpation. The navigation system itself may be inaccurate; however, the system used showed experimentally an inherent error of less than 1 mm or 1° [3]. It has also been demonstrated that the CT scan measurement might be inaccurate [22], especially with a full polyethylene cup with only a wire ring for detecting its orientation; nevertheless, this technique is well accepted as the gold standard.

However, we observed that differences between the intra-operative and post-operative measurements were small for inclination (mean of −2°, range from −12° to 9°) and is probably clinically irrelevant for most of the cases (41/48) with a difference of less than 5°. On the other hand, this difference was greater for flexion (mean of −4°, range from −25° to 19°) and might be clinically relevant for some cases (20/48) with a difference of over 5°. We suggest that the accuracy of the navigated procedure used is acceptable for inclination but must be improved for flexion.

Other systems have been proved to demonstrate a similar accuracy. Blendea et al. [2] compared non-image-based navigated and CT measurements in a laboratory study; the mean difference was 3° for inclination and 1° for flexion. Haaker et al. [6] compared intra-operative CT-based navigated and post-operative CT measurements and observed virtually no difference in the mean values of inclination and flexion in both groups; however, paired differences were not reported. Grützner et al. [5] compared C-arm-based navigated and post-operative CT measurements and reported a mean paired difference of 2° and a maximal paired difference of 6° for both inclination and flexion.

The navigation system used allowed us to position the cup in the safe zone for 87% of the cases when considering inclination alone, for 79% when considering flexion alone and for 73% of cases when considering both criteria. Haaker et al. [6], using a CT-based navigation system, reported 93% of optimal orientation for cup flexion, while the rate for inclination was not reported. Parratte and Argenson [17] reported 80% of cups implanted in the safe

zone with a non-image-based navigation system. All of these figures compare favourably with conventional implantation. A more accurate cup orientation might decrease the rate of dislocation and mechanical problems related to impingement [21].

Conclusion

The non-image-based system used in our department allowed us to define more accurately the intra-operative positioning of the acetabular cup of a total hip replacement (THR) in comparison to the computed tomography (CT) reference measurement. Inclination measurements were more accurate than the flexion measurements. A high percentage of cups were implanted in the safe zone defined prior to the study.

References

1. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B (2005) Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. *J Bone Joint Surg Br* 87:762–769
2. Blendea S, Troccaz J, Merloz P (2007) Accuracy measurements of acetabular cup positioning using CT less navigation. *Rev Chir Orthop Reparatrice Appar Mot* 93:157–164
3. Delp SL, Stulberg SD, Davies BL, Picard F, Leitner F (1998) Computer assisted knee replacement. *Clin Orthop Relat Res* 354:49–56
4. Digioia AM 3rd, Jaramaz B, Plakseychuk AY, Moody JE Jr, Nikou C, Labarca RS, Levison TJ, Picard F (2002) Comparison of a mechanical acetabular alignment guide with computer placement of the socket. *J Arthroplasty* 17:359–364
5. Grützner PA, Zheng G, Langlotz U, von Recum J, Nolte LP, Wentzensen A, Widmer KH, Wendl K (2004) C-arm based navigation in total hip arthroplasty—background and clinical experience. *Injury* 35(Suppl 1):S-A90–S-A95
6. Haaker RGA, Tiedjen K, Ottersbach A, Rubenthaler F, Stockheim M, Stiehl JB (2007) Comparison of conventional versus computer-navigated acetabular component insertion. *J Arthroplasty* 22: 151–159
7. Hirakawa K, Mitsugi N, Koshino T, Saito T, Hirasawa Y, Kubo T (2001) Effect of acetabular cup position and orientation in cemented total hip arthroplasty. *Clin Orthop Relat Res* 388:135–142
8. Honl M, Schwieger K, Salineros M, Jacobs J, Morlock M, Wimmer M (2006) Orientation of the acetabular component. A comparison of five navigation systems with conventional surgical technique. *J Bone Joint Surg Br* 88:1401–1405
9. Jenny JY, Boeri C (2003) Unicompartmental knee prosthesis implantation with a non-image-based navigation system: rationale, technique, case-control comparative study with a conventional instrumented implantation. *Knee Surg Sports Traumatol Arthrosc* 11:40–45
10. Kalteis T, Handel M, Herold T, Perlick L, Baethis H, Grifka J (2005) Greater accuracy in positioning of the acetabular cup by using an image-free navigation system. *Int Orthop* 29:272–276
11. Kalteis T, Handel M, Herold T, Perlick L, Paetzel C, Grifka J (2006) Position of the acetabular cup—accuracy of radiographic calculation compared to CT-based measurement. *Eur J Radiol* 58:294–300

12. Kalteis T, Handel M, Balthis H, Perlick L, Tingart M, Grifka J (2006) Imageless navigation for insertion of the acetabular component in total hip arthroplasty: is it as accurate as CT-based navigation. *J Bone Joint Surg Br* 88:163–167
13. Kiefer H, Othman A (2005) OrthoPilot total hip arthroplasty workflow and surgery. *Orthopedics* 28(Suppl 10):s1221–s1226
14. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR (1978) Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* 60:217–220
15. Marx A, von Knoch M, Pförtner J, Wiese M, Saxler G (2006) Misinterpretation of cup anteversion in total hip arthroplasty using planar radiography. *Arch Orthop Trauma Surg* 126:487–492
16. Mayr E, Kessler O, Prassl A, Rachbauer F, Krismer M, Nogler M (2005) The frontal pelvic plane provides a valid reference system for implantation of the acetabular cup: spatial orientation of the pelvis in different positions. *Acta Orthop* 76:848–853
17. Parratte S, Argenson JNA (2007) Validation and usefulness of a computer-assisted cup-positioning system in total hip arthroplasty. A prospective, randomized, controlled study. *J Bone Joint Surg Am* 89:494–499
18. Richolt JA, Effenberger H, Rittmeister ME (2005) How does soft tissue distribution affect anteversion accuracy of the palpation procedure in image-free acetabular cup navigation? An ultrasonographic assessment. *Comput Aided Surg* 10:87–92
19. Saragaglia D, Picard F, Chaussard C, Montbarbon E, Leitner F, Cinquin P (2001) Computer-assisted knee arthroplasty: comparison with a conventional procedure. Results of 50 cases in a prospective randomized study. *Rev Chir Orthop Reparatrice Appar Mot* 87:18–28
20. Spencer JMF, Day RE, Sloan KE, Beaver RJ (2006) Computer navigation of the acetabular component: a cadaver reliability study. *J Bone Joint Surg Br* 88:972–975
21. Sugano N, Nishii T, Miki H, Yoshikawa H, Sato Y, Tamura S (2007) Mid-term results of cementless total hip replacement using a ceramic-on-ceramic bearing with and without computer navigation. *J Bone Joint Surg Br* 89:455–460
22. Tannast M, Murphy SB, Langlotz F, Anderson SE, Siebenrock KA (2006) Estimation of pelvic tilt on anteroposterior X-rays—a comparison of six parameters. *Skeletal Radiol* 35:149–155
23. Wines AP, McNicol D (2006) Computed tomography measurement of the accuracy of component version in total hip arthroplasty. *J Arthroplasty* 21:696–701
24. Wolf A, Digioia AM 3rd, Mor AB, Jaramaz B (2005) Cup alignment error model for total hip arthroplasty. *Clin Orthop Relat Res* 437:132–137