Intra- and Intersurgeon Variability in Image-free Navigation System for THA

Hirotsugu Ohashi MD, PhD, Masanori Matsuura MD,
Yusaku Okamoto MD, PhD, Yoshiaki Okajima MD

Published online: 21 April 2009
© The Association of Bone and Joint Surgeons 2009

Abstract In image-free navigation systems, cup orientation is determined in the pelvic coordinate by registration of bony landmarks. While the value of navigation relates primarily to the reliability and accuracy of cup placement, the reliability of registration plays a role in cup placement. We therefore examined intra- and intersurgeon variability in registration and the distance between registration points in each bony landmark. Thirty-seven THAs were performed in the lateral position and 15 THAs in the supine position. The cup was fixed using a navigation system. The registration was repeated two more times by operator and assistant, and the intra- and intersurgeon variability of cup abduction angle and anteversion was analyzed by ICC (intraclass correlation coefficients). In 25 hips, the distance between intrasurgeon registration points and between intersurgeon registration points in each landmark were calculated. The ICC in the lateral position ranged between 0.59 and 0.81, and between 0.85 and 0.95 in the supine position. The ICCs of cup abduction angle for the intra- and intersurgeon variability were 0.92 and 0.95 for the supine position and 0.65 and 0.59 for the lateral position. Those of anteversion were 0.93, 0.85, and 0.81, 0.72,

respectively. The variability in locating the ASIS in the lateral position was greater than that in the supine position. The variability of registration points depended on bony landmarks and patient position but the range of variability we found would not likely result in a large variability in cup placement.

Introduction

In total hip arthroplasty (THA), malposition of the cup restricts range of motion and is the most common cause of dislocation [1, 9, 16, 20, 25, 27]. The cup abduction angle reportedly affects polyethylene wear rates [3, 13, 26] and therefore affects the rates of revision surgery [19]. Hip navigation systems have been developed to assist surgeons in determining the location and orientation (angles) of the cup in pelvic coordinates. In image-free navigation systems, three bony landmarks (typically both anterior superior iliac spines and pubic symphysis) are registered intraoperatively by manual palpation. Pelvic coordinates are based on the frontal pelvic plane defined by these bony landmarks, and the orientation of the cup is expressed in the pelvic coordinates. One of the limitations in an image-free navigation system is the variability in registration of bony landmarks since the bony landmarks are not distinct points but rather areas palpated through sheets, skin, and subcutaneous fat tissue [17, 24]. If the registration of bony landmarks is inaccurate, the final orientation of the cup determined by the navigation system will also be inaccurate. Thus, the variability of registration affects the accuracy of navigation system [21, 28].

Navigation systems have been examined in several ways to evaluate efficacy, accuracy, and variability. Efficacy has been explored by comparing freehand implantation or

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution either has waived or does not require approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

H. Ohashi (✉), M. Matsuura, Y. Okamoto, Y. Okajima
Department of Orthopaedic Surgery, Saiseikai Nakatsu Hospital,
2-10-39 Shibata, Kita-ku, Osaka 530-0012, Japan
e-mail: LU7H-OOHS@asahi-net.or.jp

mechanically guided implantation and navigated implantation [5, 7, 11, 22, 29, 30] and established when the cup was positioned within a presumed safe zone or when the deviations from the desired cup position occurred. Accuracy has been determined by comparing the intraoperative measurement by the navigation system to the postoperative measurement on plain radiograph or CT scan, assuming the radiograph or CT scan are gold standards [2, 6, 14, 18, 33]. The difference of the angles between what is known on the gold standard and what is discerned by the navigation system indicates the accuracy. In contrast, variability has not been frequently reported. Variability has been explored by comparing the variation of cup orientation from the desired range using manual methods compared to an initial group of navigation cases and subsequent group [21].

Navigation based on preoperative CT images or intraoperative fluoroscopic images, or imageless techniques based on palpation of the landmarks reduces the number of outliers of cup position compared to conventional manual techniques [30]. CT-based navigation has advantages in terms of pelvic orientation, although image-free navigation is reportedly as reliable as CT-based navigation in positioning the acetabular component [11, 32]. However, reliable and accurate registration of bony landmarks is important for the accuracy in image-free navigation systems. The intra- and intersurgeon variability of registration points in each bony landmark will influence cup abduction angle and anteversion. If we know which bony landmark is more variable for registration, we should make an effort to obtain more reliable registration.

We therefore determined (1) the intra- and intersurgeon variability in registering landmarks with two surgical positions and (2) the distance between intrasurgeon registration points and the distance between intersurgeon registration points in each bony landmark.

Materials and Methods

We performed 37 THAs through a direct lateral approach in the lateral decubitus position and 15 through modified Smith-Petersen direct anterior approach in the supine position. Gender, age, and BMI were not different between two groups (Table 1). The main indication for surgery of those hips operated in lateral decubitus position was osteoarthritis. The indications for direct anterior approach were limited to osteoarthritis of Crowe types 1 and 2, and the other etiologies without flexion contracture. The hips outside the indications for direct anterior approach were operated through direct lateral approach.

All surgery was performed by two experienced surgeons (HO and MM). We used the image-free OrthoPilot hip navigation system (B. Braun Aesculap, Tuttlingen,

Table 1. Demographic data

Variable	Lateral decubitus position	Supine position
Number of hips	37	15
Gender (male/female ratio)	8/29	5/10
Average age in years (range)	57.9 (42–65)	54.6 (34–63)
Average BMI in kg/m ² (range)	23.1 (17–28.3)	22.8 (17.1–29.5)
Etiology (hips)		
OA	34	8
AVN	2	4
Fx	1	2
RA	0	1

Germany) for cup positioning. The first registration was performed by the surgeon. The cup was fixed using the navigation system as usual, and the cup abduction angle and anteversion indicated on the navigation screen were recorded as Abduction-1 and Anteversion-1. Then, the assistant registered the bony landmarks, and the cup position angles were recalculated in reference to the second registration (Abduction-2, Anteversion-2). Finally, the surgeon again registered the bony landmarks, and the cup position angles were recalculated in reference to the third registration (Abduction-3, Anteversion-3). The difference of the angles indicated by the navigation system corresponded to the difference in registration, thus the intrasurgeon variability in registration was evaluated by comparing Abduction-1 to Abduction-3 and Anteversion-1 to Anteversion-3, and the intersurgeon variability was evaluated by comparing Abduction-2 to Abduction-3 and Anteversion-2 to Anteversion-3. Intra- and intersurgeon variability was determined by calculating by ICC (intra-class correlation coefficients).

In each registration, 3-D coordinates of the active infrared light-emitting tracker on the ilium, not in the pelvic coordinates, were established. From the data provided by the navigation system, each registration point and cup position were calculated and expressed in the 3-D coordinates from the correspondent registration. The distance between registration points was calculated in reference to the cup position, because the cup was not touched during second and third registration. Unfortunately, the registration data was deleted by the next registration data in the first 27 cases due to a technical error of the software. Thus, the registration points in three bony landmarks were calculated in the 25 cases that followed. Sixteen of these 25 hips were operated in the lateral decubitus position and nine in the supine position. The distance between registration points at first and third registration in each bony landmark was defined as the intrasurgeon distance of registration points and that

between registration points at second and third registration was defined as the intersurgeon distance of registration points. The data obtained in the lateral decubitus position and in the supine position were analyzed with one-way factorial ANOVA test. SPSS version 16.0 software (SPSS, Chicago, Ill.) was used for statistical analysis.

Results

We observed no difference in average cup abduction angle and anteversion between surgeons in either the lateral decubitus position or the supine position (Table 2). The ICC in the lateral decubitus position ranged between 0.59 and 0.81 and that in the supine position ranged between 0.85 and 0.95 (Table 3). The ICCs of cup abduction angle for the intra- and intersurgeon variability for the supine position were higher than those for the lateral decubitus position. The ICCs of cup anteversion for the intrasurgeon variability were greater than those for the intersurgeon variability in both positions.

There was no difference in the intra- and intersurgeon distance of registration points in each bony landmark in two surgical positions (Table 4). The intra- and intersurgeon distance in collateral and contralateral ASIS were similar in the lateral decubitus position. The intra- and intersurgeon distance of registration points in collateral ASIS and the intrasurgeon distance of registration points in contralateral ASIS in the supine position were smaller than

those in the lateral decubitus position. In the pubic symphysis, the intrasurgeon distance of registration points was smaller than intersurgeon distance, and the intra- and intersurgeon distance were not improved in the supine position.

Discussion

In image-free navigation systems, accuracy of cup position has been improved [11, 32]. However, the registration of bony landmarks is critical for the accuracy, and the variability of registration points in each bony landmark affects both cup abduction angle and anteversion. We firstly determined the intra- and intersurgeon variability in registration with two surgical positions. To know which bony landmark is more variable for registration is one strategy for improving accuracy. We secondly determined the distance between intrasurgeon registration points and the distance between intersurgeon registration points in each bony landmark.

One limitation of this study was that the indications for direct anterior approach and direct lateral approach were different and the deformity of hips operated through direct anterior approach was relatively mild. Despite the difference in severity of hip deformity and relatively low BMIs (which would influence the variability of registration [23]) we found no difference between the two groups. Second, since the registration data obtained from the first 27 cases was missing, the sample size of the intra- and intersurgeon variability of distance between registration points was reduced. Third, the BMI in this series was low compared to that of European and American populations. Since the thick subcutaneous fat tissue makes registration difficult [17], further study is necessary for obese patients. Fourth, the ranges of variability in registration will not greatly influence the actual cup position: one study reported a registration difference of 1 cm anterior to the bony landmark at the ipsilateral ASIS, contralateral ASIS, and the center of the two pubic tubercles resulted in 1.4°, 0.2° and −0.2° in abduction and 1.8°, 4.4° and −6.8° in anteversion,

Table 2. Average cup abduction angle and anteversion in each registration

Type of measurement	Lateral decubitus position (n = 37)	Supine position (n = 15)
Abduction-1	39.1 ± 4.1	40.3 ± 3.3
Abduction-2	38.3 ± 4	39.3 ± 3.3
Abduction-3	37 ± 5.3	39.3 ± 4.3
Anteversion-1	15.9 ± 4.5	16.4 ± 4.4
Anteversion-2	15.9 ± 5.5	16 ± 5.8
Anteversion-3	14.7 ± 5.3	15.7 ± 4.7

Table 3. Intraclass correlation coefficients

Position	Abduction	Anteversion
<i>Lateral decubitus</i> (n = 37)		
Intrasurgeon	0.65	0.81
Intersurgeon	0.59	0.72
<i>Supine</i> (n = 15)		
Intrasurgeon	0.92	0.93
Intersurgeon	0.95	0.85

Table 4. Variability of distance in each landmark

Position	Collateral ASIS	Pubic symphysis	Contralateral ASIS
<i>Lateral decubitus</i> (n = 16)			
Intrasurgeon	1.3 ± 1 (cm)	1.4 ± 0.7	1.5 ± 1.3
Intersurgeon	1.2 ± 0.7	1.6 ± 1.2	1.3 ± 0.8
<i>Supine</i> (n = 9)			
Intrasurgeon	0.7 ± 0.5	1.1 ± 0.7	0.8 ± 0.5
Intersurgeon	0.8 ± 0.5	1.5 ± 1.1	1.2 ± 0.6

Table 5. Reported clinical results of the cup abduction angle and anteversion using image-free navigation system

Author (year)	Number of hips	Abduction Average $\pm$ SD (range)	Anteversion Average $\pm$ SD (range)
Lateral			
Wixson and MacDonald [31] (2005)	82	42.2 $\pm$ 4.7	21 $\pm$ 7.3
Dorr et al. [4] (2005)	110	39.1 $\pm$ 4.4 (28–53)	23.6 $\pm$ 3.8 (15–35)
Najarian et al. [21] (2009) ^a	49	44.1 $\pm$ 6.2 (30–58)	24.1 $\pm$ 5.9 (13–36)
Najarian et al. [21] (2009) ^b	47	45.5 $\pm$ 4.7 (30–56)	25.1 $\pm$ 5.9 (13–36)
Supine			
Kalteis et al. [12] (2005)	23	45 $\pm$ 2.8 (40–50)	14.4 $\pm$ 5 (5–25)
Kalteis et al. [11] (2006)	30	43.2 $\pm$ 4 (33–50)	15.2 $\pm$ 5.5 (5–25)
Judet [10] (2007)	38	46 $\pm$ 2	16 $\pm$ 3
Hasart et al. [8] (2008)	30	43.2 (38.1–47.0)	25 (13.8–30.5)

^a Results from the initial series; ^b results from the second series.

respectively [17]. Our data suggest the intra- and intersurgeon distance of registration points in collateral ASIS was less than 1 cm in supine position. While the intra- and intersurgeon distance of registration points were 5.4 cm and 3.2 cm, respectively, in our worst case, we had fortunately no outlier in our cases. Since the registration points in three bony landmarks were expressed in 3-D coordinates of the tracker in our study, the direction of the variability between registration points in the pelvic coordinates could not be calculated. If we can transform the coordinates of the tracker to the pelvic coordinates, the direction of the variability of registration might be evaluated.

We found the ICCs of cup abduction angle for the intra- and intersurgeon variability in the supine position were greater than those in the lateral decubitus position. The orientation of cups using an image-free navigation system has been reported and the abduction angle and anteversion were categorized in terms of surgical position (Table 5) [4, 8, 10–12, 21, 31]. Focusing on the range and the standard deviation of abduction angle and anteversion, abduction angle in the supine position indicated narrower range and smaller standard deviation. Taking these reported clinical results, the variability of registration was influenced by the surgical position.

Intra- and intersurgeon variability of registration has been reported in a cadaver study in the lateral position [28]. The difference among eight surgeons was substantial, perhaps owing to the fact that the eight surgeons (four consultants and four senior registers) had differing levels of experience with hip navigation. The variation of cup orientation was larger for anteversion than for abduction angle, and the intra- and interobserver variability in cup orientation was larger for anteversion than for inclination. We found the ICCs for the intra- and intersurgeon variability in lateral position were larger for anteversion than for abduction angle in our study. The patient positioner and surgical

sheets for the operation might affect the registration in both ASIS. The other cadaver study was performed in supine position [24]. The authors reported acceptable intraobserver repeatability but acceptable interobserver analysis agreement only in the abduction angle and not in anteversion. These results were similar to our clinical results.

To overcome the variability of percutaneous manual palpation, the use of ultrasound is proposed as one solution. Ultrasound shows the shape of bony landmarks and the registration may then be performed on an ultrasound screen connected to the navigation system [15]. The deviation in registration is reportedly reduced [8, 15, 24]. Ultrasound, however, is still under development and limited to use in the supine position.

We found the ICCs of cup abduction angle and anteversion for the intra- and intersurgeon variability in the supine position were higher than those in the lateral decubitus position. Focusing on each bony landmark, the intra- and intersurgeon distance of registration points in collateral ASIS and the intrasurgeon distance in contralateral ASIS in the lateral position were reduced in the supine position, while the intra- and intersurgeon distance of registration points in pubic symphysis were not improved in the supine position. If the registration of bony landmarks is inaccurate, the final orientation of the cup determined by the navigation system will also be inaccurate. In image-free navigation systems, the registrations of pubic symphysis in the supine position and all bony landmarks in the lateral decubitus position need further improvement.

References

1. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B. Reducing the risk of dislocation after total hip arthroplasty. The effect of orientation of the acetabular component. *J Bone Joint Surg Br.* 2005;87:762–769.

2. Blendea S, Troccaz J, Ravey JN, Merloz P. Image-free cup navigation inaccuracy: a two-study approach. *Comput Aided Surg.* 2007;12:176–180.
3. Del Schutte H Jr, Lipman AJ, Bannar SM, Livermore JT, Ilstrup D, Morrey BF. Effects of acetabular abduction on cup wear rates in total hip arthroplasty. *J Arthroplasty.* 1998;13:621–626.
4. Dorr LD, Hishiki Y, Wan Z, Newton D, Yun A. Development of imageless computer navigation for acetabular component position in total hip replacement. *Iowa Orthop J.* 2005;25:1–9.
5. Ecker TM, Tannast M, Murphy SB. Computed tomography-based surgical navigation for hip arthroplasty. *Clin Orthop Relat Res.* 2007;465:100–105.
6. Grützner PA, Zheng G, Langlotz U, von Recum J, Nolte LP, Wentzensen A, Widmer KH, Wendl K. C-arm based navigation in total hip arthroplasty-background and clinical experience. *Injury.* 2004;35 Suppl 1:S-A90-95.
7. Haaker RG, Tiedjen K, Ottersbach A, Rubenthaler F, Stockheim M, Stiehl JB. Comparison of conventional versus computer-navigated acetabular component insertion. *J Arthroplasty.* 2007;22:151–159.
8. Hasart O, Perka C, Tohtz S. Comparison between pointer-based and ultrasound-based navigation technique in THA using a minimally invasive approach. *Orthopedics.* 2008;31(10 Suppl):S31–S34. OrthoSupersite Web site. Available at: <http://www.orthosupersite.com/view.asp?rID=35540>. Accessed October 2008.
9. Jolles BM, Zangger P, Leyvraz PF. Factors predisposing to dislocation after primary total hip arthroplasty. A multivariate analysis. *J Arthroplasty.* 2002;17:282–288.
10. Judet H. Five years of experience in hip navigation using a minimally invasive anterior approach. *Orthopedics.* 2007;30(10 Suppl):S141–143.
11. Kalteis T, Handel M, Balthis H, Perlick L, Tingart M, Grifka J. 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.* 2006;88:163–167.
12. Kalteis T, Handel M, Herold T, Perlick L, Baethis H, Grifka J. Greater accuracy in positioning of the acetabular cup by using an image-free navigation system. *Int Orthop.* 2005;29:272–276.
13. Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. *J Arthroplasty.* 1998;13:530–534.
14. Kiefer H, Othman A. The Orthopilot navigation system for primary Bicontact total hip replacement. *Z Orthop Unfall.* 2007;145 Suppl 1:S49–S152.
15. Kiefer H, Othman A. Ultrasound vs pointer palpation based method in THA navigation: a comparative study. *Orthopedics.* 2007;30(10 Suppl):S153–S156.
16. Kummer FJ, Shah S, Iyer S, DiCesare PE. The effect of acetabular cup orientations on limiting hip rotation. *J Arthroplasty.* 1999;14:509–513.
17. Lee YS, Yoon TR. Error in acetabular socket alignment due to the thick anterior pelvic soft tissues. *J Arthroplasty.* 2008;23:699–706.
18. Lin F, Lim D, Wixson RL, Milos S, Hendrix RW, Makhosous M. Validation of a computer navigation system and a CT method for determination of the orientation of implanted acetabular cup in total hip arthroplasty: A cadaver study. *Clin Biomech (Bristol, Avon).* 2008;23:1004–1011.
19. Malchau H, Herberts P, Ahnfelt L. Prognosis of total hip replacement in Sweden. Follow-up of 92,675 operations performed 1978–1990. *Acta Orthop Scand.* 1993;64:497–506.
20. McCollum DE, Gray WJ. Dislocation after total hip arthroplasty. Causes and prevention. *Clin Orthop Relat Res.* 1990;261:159–170.
21. Najarian BC, Kilgore JE, Markel DC. Evaluation of component positioning in primary total hip arthroplasty using an imageless navigation device compared with traditional methods. *J Arthroplasty.* 2009;24:15–21.
22. Nogler M, Kessler O, Prassl A, Donnelly B, Streicher R, Sledge JB, Krismer M. Reduced variability of acetabular cup positioning with use of an imageless navigation system. *Clin Orthop Relat Res.* 2004;426:159–163.
23. Parratte S, Argenson J-NA. Validation and usefulness of a computer-assisted cup-positioning system in total hip arthroplasty. A prospective, randomized, controlled study. *J Bone Joint Surg Am.* 2007;89:494–499.
24. Parratte S, Kikian P, Pauly V, Champsaur P, Argenson J-NA. The use of ultrasound in acquisition of the anterior pelvic plane in computer-assisted total hip replacement. A cadaver study. *J Bone Joint Surg Br.* 2008;90:258–263.
25. Paterno SA, Lachiewicz PF, Kelley SS. The influence of patient-related factors and the position of the acetabular component on the rate of dislocation after total hip replacement. *J Bone Joint Surg Am.* 1997;79:1202–1210.
26. Patil S, Bergula A, Chen PC, Colwell CW Jr, D'Lima DD. Polyethylene wear and acetabular component orientation. *J Bone Joint Surg Am.* 2003;85:56–63.
27. Pierchon F, Pasquier G, Cotten A, Fontaine C, Clarisse J, Duquenne A. Causes of dislocation of total hip arthroplasty. CT study of component alignment. *J Bone Joint Surg Br.* 1994;76:45–48.
28. Spencer JMF, Day RE, Sloan KE, Beaver RJ. Computer navigation of the acetabular component. A cadaver reliability study. *J Bone Joint Surg Br.* 2006;88:972–975.
29. Tannast M, Langlotz F, Kubiak-Langer M, Langlotz U, Siebenrock KA. Accuracy and potential pitfalls of fluoroscopy-guided acetabular cup placement. *Comput Aided Surg.* 2005;10:329–336.
30. Wixson RL. Computer-assisted total hip navigation. *Instr Course Lect.* 2008;57:707–720.
31. Wixson RL, MacDonald MA. Total hip arthroplasty through a minimal posterior approach using imageless computer-assisted hip navigation. *J Arthroplasty.* 2005;20 Suppl 3:51–56.
32. Ybinger T, Kumpan W. Enhanced acetabular component positioning through computer-assisted navigation. *Int Orthop.* 2007;Suppl 1:S35–S68.
33. Ybinger T, Kumpan W, Hoffart HE, Muschalik B, Bullmann W, Zweymüller K. Accuracy of navigation-assisted acetabular component positioning studied by computed tomography measurements: methods and results. *J Arthroplasty.* 2007;22:812–817.