

HIP COMPASS[®]: A Mechanical Intraoperative Navigation Guide Associated with Improved Revision-Free Implant Survivorship after Ceramic-on-Ceramic Total Hip Arthroplasty at Minimum 10-Year Follow-up

Yoshiaki Tei^a, Norio Imai^{b*}, Keishi Kimura^a, Yuki Hirano^a,
Yoji Horigome^b, Ken Suda^a, and Hiroyuki Kawashima^a

Divisions of ^aOrthopedic Surgery, Department of Regenerative and Transplant Medicine,

*^bComprehensive Musculoskeletal Medicine, Niigata University Graduate School of Medical and Dental Sciences,
Niigata 951-8510, Japan*

HIP COMPASS[®] has demonstrated improved accuracy in intraoperative support for the acetabular component insertion angle. We assessed long-term revision-free implant survivorship following total hip arthroplasty (THA) using HIP COMPASS, with ≥ 10 years of follow-up. We retrospectively analyzed 210 hips of 186 patients who underwent cementless THA with ceramic-on-ceramic bearing couples, with or without HIP COMPASS. The mean follow-up duration was 10.8 years in the HIP COMPASS group and 12.7 years in the control group. Overall, 86.0% and 78.2% of cups were placed within Lewinnek's safe zone with and without HIP COMPASS, respectively. Variability in radiographic inclination and anteversion was greater in the control group than in the HIP COMPASS group. Dislocation rates were 3.2% in the control group and 1.2% in the HIP COMPASS group, with no significant difference between groups. The control group had a significantly higher revision rate than the HIP COMPASS group (7.3% vs. 1.2%). Use of HIP COMPASS was associated with improved long-term revision-free implant survivorship over ≥ 10 years and more consistent acetabular component positioning at an appropriate insertion angle, which may contribute to stable initial fixation.

Key words: HIP COMPASS[®], survivorship, total hip arthroplasty, ceramic-on-ceramic

Precise placement of components in total hip arthroplasty (THA) is essential for long-term implant survivorship [1-3]. Impingement of the femoral neck on the rim of the acetabular cup can cause dislocation and accelerate cup loosening [4,5]. Edge loading resulting from excessive cup inclination or anteversion increases the risk of accelerated wear and bearing failure, even with modern wear-resistant materials such as metal-on-metal bearings [6], ceramic-on-ceramic (CoC) bearings [7], or highly cross-linked

polyethylene [8]. Improving the accuracy of acetabular component placement may reduce dislocation frequency and loosening risks, thereby enhancing long-term implant survival [1].

Navigation systems enhance surgical precision; however, their high cost, technical complexity, and limited adoption in routine clinical practice restrict widespread use. In Japan, as of 2023, CT-based navigation and imageless navigation were used in only 14.5% and 17.4% of primary total hip arthroplasties, respectively [9], indicating that the adoption of naviga-

Received August 18, 2025; accepted March 19, 2026.

*Corresponding author. Phone: +81-25-227-2272; Fax: +81-25-227-0782
E-mail: imainorio2001@yahoo.co.jp (N. Imai)

Conflict of Interest Disclosures: No potential conflict of interest relevant to this article was reported.

tion systems remains limited [10]. To address this challenge, we developed HIP COMPASS® (Mizuho Corp., Ltd., Tokyo, Japan), a simple and cost-effective mechanical intraoperative angle guide designed to assist in controlling acetabular cup orientation during supine THA. HIP COMPASS was introduced in 2010 and has been shown to reduce insertion angle error: in a previous study, radiographic anteversion and inclination errors were 2.9° each in the HIP COMPASS group, compared with 8.8° and 6.1°, respectively, in the non-HIP COMPASS group [11]. However, the long-term survivorship of THA performed using HIP COMPASS remains unclear. Therefore, in this study, we aimed to examine revision-free implant survivorship, dislocation incidence, revision rate, and acetabular component angles following CoC THA using HIP COMPASS in patients with ≥ 10 years of follow-up. We hypothesized that long-term revision-free implant survivorship would be superior in the HIP COMPASS compared with the non-HIP COMPASS group, owing to more accurate acetabular component placement.

Materials and Methods

Participants. We retrospectively reviewed 210 consecutive hips in 186 patients who underwent THA at our institution between March 1, 2008, and December 31, 2013 and were followed up for ≥ 10 years. Use of HIP COMPASS began on April 1, 2011. Based on the date of surgery, we divided patients into two groups: the control group (124 hips in 116 patients), who underwent THA between March 1, 2008, and March 31, 2011, and the HIP COMPASS group (86 hips in 70 patients), who underwent surgery between April 1, 2011, and December 31, 2013 (Fig. 1). Exclusion criteria included cases that required structural bone grafting during the study period. In addition, cases in which CT-based navigation was used were excluded: eight cases performed between March 1, 2008, and March 31, 2011, and five cases performed between April 1, 2011, and December 31, 2013. Among the 210 hips, 172 were in 159 female patients, and 38 were in 27 male patients. We assessed revision-free implant survivorship, dislocation incidence, and causes of dislocation in patients with ≥ 10 years of follow-up.

Ethics. The Institutional Review Board of the authors' affiliated institution approved the study protocol (approval no. 2024-0265) and waived the require-

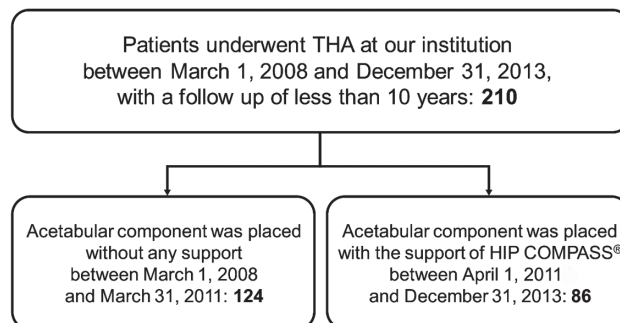


Fig. 1 Flow diagram of the participant selection process.

ment for informed consent owing to the retrospective, observational, and non-interventional nature of the study. All methods used in this study were performed in accordance with the relevant guidelines and regulations.

HIP COMPASS. HIP COMPASS is a mechanical intraoperative support device consisting of a T-plate with three uniformly sized adjustable legs and an attachable angle indicator (Fig. 2). The legs can be repositioned along the plate, allowing the T-plate to align parallel to the anterior pelvic plane (APP) by applying pressure to the anterior-superior iliac spine (ASIS) and pubic symphysis (PS). However, variations in soft tissue thickness between the ASIS and PS can introduce alignment errors between the T-plate and the APP. To address this, we assessed the soft tissue thickness at both ASISs and the PS. We then calculated the difference between the PS thickness and the average thickness of the bilateral ASISs. This difference was used to adjust the length of the leg on the PS side, thereby correcting any alignment error between the APP and the T-plate. The target inclination and anteversion angles of the acetabular cup were based on the functional pelvic plane (FPP). The angle indicator was set to the corresponding angles expressed relative to the APP [12]. It was then mounted on the T-plate after the T-plate was aligned parallel to the APP, to denote the desired cup implantation angle. During surgery, the acetabular cup was positioned by aligning the cup holder parallel to the indicator.

Concept of the planning. We conducted three-dimensional preoperative planning for all cases using either HipCAS® or ZedView® (Lexi, Tokyo, Japan) [13,14]. The radiographic inclination was set at 40°, and radiographic anteversion was 15-20° relative to the

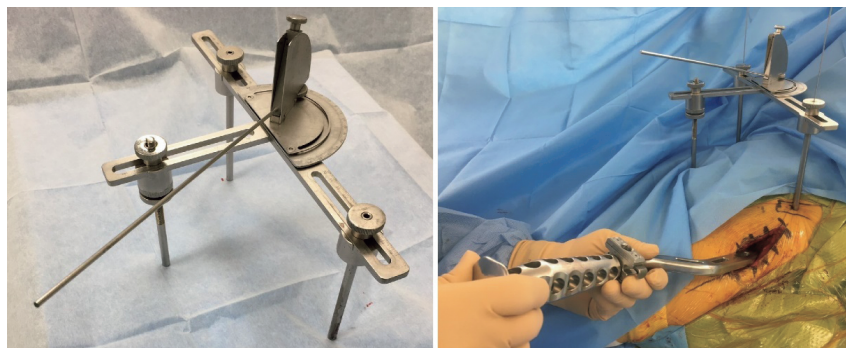


Fig. 2 HIP COMPASS. The device had legs on the left and right anterior-superior iliac spine and pubic symphysis (the width of the former and height of the latter were variable). The length of the leg placed on the pubis was also adjustable.

FPP. The femoral component was positioned with 10–30° of anteversion relative to the retrocondylar plane (RCP), defined by the most posterior points of the bilateral posterior condyles and the most posterior point of the greater trochanter. This alignment is crucial to prevent implant impingement, which may lead to dislocation following THA [3, 15, 16]. All surgeries were performed using an anterolateral supine approach under general anesthesia. We implanted uncemented acetabular components (Plasmacup[®] MSC; B. Braun SE, Germany) and ceramic liners (BIOLOX[®] forte; CreamTec GmbH, Germany). The femoral component was selected from three implant types — BiCONTACT N, BiCONTACT D, and Trilliance cemented stem — tailored to the specific anatomical configuration of each femur. All femoral heads measured 32 mm in diameter and were made of ceramic (BIOLOX[®] forte; CreamTec GmbH).

Measurements. We used ZedView[®] software (Lexi) to assess the implantation angles — specifically, the inclination and anteversion of the acetabular component and the anteversion of the femoral component. This analysis was based on three-dimensional (3D) digital bone models reconstructed from computed tomography (CT) scans obtained 1-week post-surgery [13, 14].

We acquired approximately 600 CT slices (slice thickness: 1.25 mm) for each limb using a multi-slice scanner with a 64-row detector (Aquilion 64TM; Toshiba Medical Systems, Otawara, Japan).

Using these CT data, we developed 3D surface models of the pelvis and femur for each patient. To assess the orientation of the acetabular component, specifically its inclination and anteversion, we aligned

the pelvic model with the APP, defined by the bilateral anterior superior iliac spines and the PS, ensuring that all three landmarks lay in the same horizontal plane [17]. The 3D femoral model was adjusted to align with the RCP, as previously described [18].

Survey items. We assessed the incidence and timing of postoperative dislocation, the revision rate, the causes of revision, and time to revision. Revision was performed/considered if there was component migration of $\geq 10^\circ$ or > 3 mm on plain radiographs, symptomatic loosening (*e.g.*, pain, noise, or discomfort), or recurrent dislocation that interfered with daily activities. We defined early failure potentially related to initial malposition as cup dislocation or radiographic loosening occurring within 3 months after THA, based on reports that the acetabulum and acetabular component typically stabilize within that period. In contrast, aseptic loosening was defined as radiographic or clinical loosening occurring more than 3 months postoperatively, such as component migration of $\geq 10^\circ$ or > 3 mm or symptomatic loosening. Postoperative dislocation was analyzed separately as a complication [19, 20].

Statistical analysis. We compared insertion angles between the control and HIP COMPASS groups using an independent-samples *t*-test. An F-test was used to assess variability in the insertion angles. The proportion of cases within the Lewinnek safe zone was compared between groups, and revision and dislocation rates were compared using Fisher's exact test (two-tailed). Revision-free implant survivorship (end-point: first revision) was analyzed using the Kaplan–Meier method and compared between groups using the

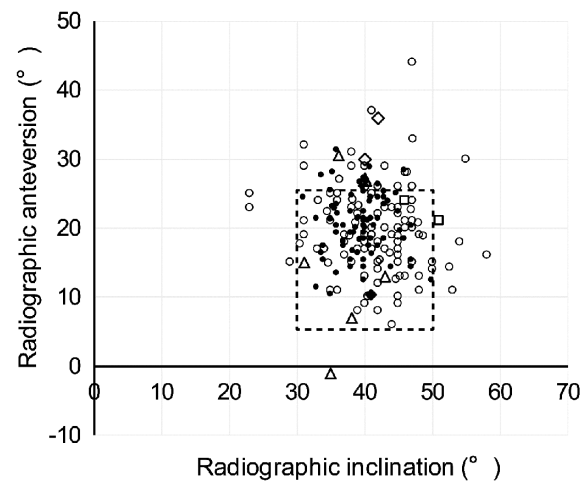
log-rank test.

A post hoc power analysis was performed to evaluate the risk of Type II error (β). For the t -test, we defined the effect size (d) as 0.5 and type I error (α) as 0.05. For the Fisher's exact test, we defined the effect size as 0.3 and the Type I error as 0.05. Intra- and inter-rater reliabilities were evaluated for each parameter using intra-class correlation coefficients (ICCs). Intra-rater reliability was evaluated by having the same observer (YT) repeat the measurements at intervals of at least 1 week. Inter-rater reliability was evaluated by having a second observer (NI) perform the same measurements. All statistical analyses were conducted using SPSS Version 28 (SPSS Inc., Chicago, IL, USA).

Results

Participant characteristics are presented in Table 1.

Radiographic inclination was significantly greater in the control group, while there was no significant difference between the groups in either radiographic anteversion or stem anteversion (Table 2). The proportions of cases within the Lewinnek safe zone were 78.2% in the control group and 86.0% in the HIP COMPASS group (Fig. 3). The proportion of cases within the Lewinnek safe zone was significantly higher in the HIP COMPASS group than in the control group ($p=0.016$). The HIP COMPASS group had 10 outliers (defined as cases



Control group

- No dislocation, no revision THA
- △ Revision THA
- Dislocation
- ◇ Patients with dislocation, consequently, underwent revision THA

HIP COMPASS group

- No dislocation, no revision THA
- ◆ Patients with dislocation, consequently, underwent revision THA
- Safe zone described by Lewinnek

Fig. 3 Scatter plot of radiographic inclination and radiographic anteversion of the acetabular component. With the HIP COMPASS, 74 cups were placed within the safe zone of Lewinnek, and without the HIP COMPASS, 97 cups were placed within this zone.

Table 1 Characteristics of participants

	HIP COMPASS group (n=86)	Control group (n=124)	P-value
Age (years)	59.0 ± 10.2	58.8 ± 10.3	0.894*
Sex (male/female)	16/70	18/106	0.407†
Body mass index (kg/m ²)	23.7 ± 3.2	23.2 ± 3.3	0.802*
Follow up period (years)	10.8 ± 1.4	12.7 ± 1.5	<0.001*
Cause	Hip osteoarthritis: 68 Idiopathic osteonecrosis of the femoral head: 18	Hip osteoarthritis: 107 Idiopathic osteonecrosis of the femoral head: 17	

*, an independent-sample t -test; †, Fisher's exact probability test.

Table 2 Component orientation

	HIP COMPASS group	Control group	P-value
Radiographic inclination (°)	39.7 ± 3.7	41.6 ± 5.9	0.001
Radiographic anteversion (°)	21.0 ± 4.5	19.7 ± 6.9	0.147
Stem anteversion (°)	16.2 ± 12.3	19.0 ± 11.4	0.143

with a radiographic inclination or anteversion error exceeding 10°) among the 86 patients (11.7%), while the control group had 31 outliers among 124 patients (25.0%).

Specifically, for inclination errors exceeding 10°, there were no outliers (0.0%) in the HIP COMPASS group and nine outliers (10.5%) in the control group ($p=0.011$). For anteversion errors exceeding 10°, there were 10 outliers (11.7%) in the HIP COMPASS group and 22 outliers (17.7%) in the control group ($p=0.225$). The F-test revealed significantly greater variance in both radiographic anteversion ($F=2.44$, $p<0.001$) and radiographic inclination ($F=2.29$, $p<0.001$) in the control group.

There were four dislocations (4/124; 3.2%) in the control group and one (1/86; 1.2%) in the HIP COMPASS group during the follow-up period; the difference between groups was not statistically significant ($p=0.651$). All dislocations occurred within 3 months postoperatively (Table 3).

Revision surgery was significantly more frequent in the control group (9/124, 7.3%) than in the HIP COMPASS group (1/86, 1.2%) ($p=0.049$) (Table 3). The causes of revision in the control group were recurrent dislocation ($n=2$), aseptic loosening ($n=2$), poor fixation due to initial malposition ($n=2$), ceramic liner breakage ($n=2$), and squeaking ($n=1$). The single revision in the HIP COMPASS group was due to poor fixation related to initial malposition.

Consequently, Kaplan–Meier analysis showed higher revision-free implant survivorship in the HIP COMPASS group (Fig. 4). The mean time to revision was 3.35 years (range: 0.1–9.0 years) in the control group and 0.1 years in the HIP COMPASS group.

Post hoc analysis yielded statistical power of 0.941 for the *t*-test and 0.940 for Fisher's exact test. Intra- and

interobserver reliability for all measured parameters was excellent (Table 4). The intraclass correlation coefficients (ICCs) for intraobserver reliability ranged from 0.956 to 0.974, and those for interobserver reliability ranged from 0.932 to 0.950 (all $p<0.001$). The mean absolute differences were small for all parameters, indicating high measurement reproducibility.

Discussion

The findings of this study indicate that the revision-free implant survivorship after THA performed using the HIP COMPASS system is superior to that after

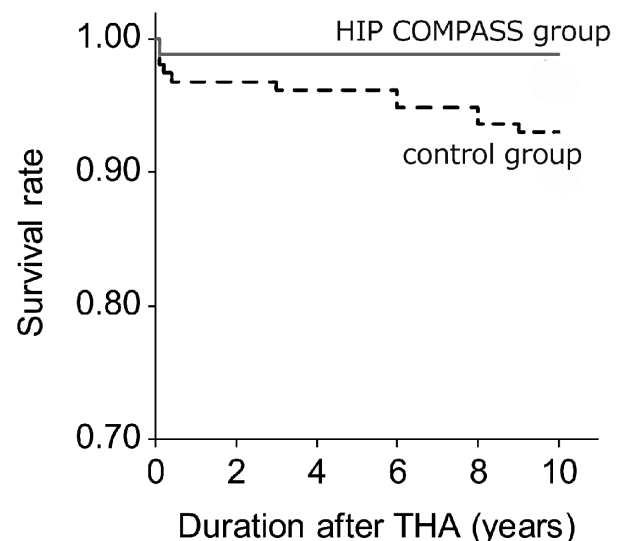


Fig. 4 Kaplan–Meier curve of revision-free implant survivorship. Revisions were more frequent in the control group than the HIP COMPASS group; consequently, revision-free survivorship was higher in the HIP COMPASS group.

Table 3 Rate of dislocation, survivorship, and revision THA and the cause

	HIP COMPASS group (n = 86)	Control group (n = 124)	P-value
Dislocation (cases)	1.2% (1/86)	3.2% (4/124)	0.651
Survivorship (cases)	98.8% (84/86)	92.7% (115/124)	0.049
Revision THA (cases)	1.2% (1/86)	7.3% (9/124)	0.049
Cause	Poor fixation due to initial malposition: 1	Poor fixation due to initial malposition: 2 Recurrent dislocation: 2 Aseptic loosening: 2 Breakage of ceramic liner: 2 Squeaking without breakage: 1	

THA, total hip arthroplasty.

Table 4 Intra- and interobserver reliability of measurement values

	Intra observe reliability				Interobserver reliability			
	MAD	ICC	95% CI	P-value	MAD	ICC	95% CI	P-value
Radiographic anteversion (°)	1.4 ± 0.8	0.971	0.962–0.978	<0.001	1.9 ± 1.4	0.932	0.912–0.945	<0.001
Radiographic inclination (°)	1.3 ± 0.9	0.974	0.963–0.980	<0.001	2.3 ± 1.8	0.941	0.922–0.956	<0.001
Stem anteversion (°)	1.6 ± 1.6	0.956	0.934–0.978	<0.001	2.2 ± 2.1	0.950	0.933–0.962	<0.001

MAD, mean absolute difference; ICC, interclass correlation coefficient; CI, confidence interval.

THA performed without it over a minimum 10-year follow-up period. This outcome supports our initial hypothesis. The variance in radiographic inclination and anteversion was significantly lower in THA performed with HIP COMPASS, consistent with previous findings [11]. Earlier studies have demonstrated an association between accurate cup placement and improved clinical outcomes in THA when using other navigation systems; however, many of these investigations were limited to short- or mid-term follow-up periods [21–26].

In contrast, Imai *et al.* [27] and Sugano *et al.* [1] have reported long-term outcomes following THA with CT-based navigation systems, suggesting a potential contribution to enhanced implant longevity. Our study demonstrates that HIP COMPASS provided greater precision in acetabular cup orientation than the control procedure. Furthermore, its use was associated with improved revision-free survivorship in THA with CoC bearing surfaces, based on follow-up of ≥ 10 years.

The lower revision rate observed in the HIP COMPASS group may be partially explained by improved acetabular component orientation. Revisions related to poor initial fixation and early instability may be associated with suboptimal cup positioning. The reduced variability in cup inclination and anteversion achieved with HIP COMPASS may have contributed to improved initial stability and, in turn, to fewer revisions. Although ceramic liner breakage and squeaking are considered multifactorial complications, implant malposition has been reported as a potential contributing factor [28–30]. This may explain why these revision causes were observed exclusively in the control group in the present study.

Although the dislocation rate was lower in the HIP COMPASS group (1.2%) than in the control group (3.2%), this difference did not reach statistical significance. Given the low overall incidence of dislocation

events, the sample size in this study may have been insufficient to detect a statistically significant difference between the groups. Previous studies have reported dislocation rates after THA ranging from 1.5% to 3.9% [21,31–36]. However, dislocation rates of 0.4–1.0% have been reported for total hip arthroplasty performed using the anterolateral supine approach during a similar period [33–36]. In the present study, the dislocation rate in the HIP COMPASS group was comparable to these previously reported rates, whereas the dislocation rate in the control group was higher. This finding may suggest that increased variability in component orientation that may reflect reduced placement accuracy of acetabular component placement in the control group may have contributed to the increased dislocation rate. The rates observed in both the control and HIP COMPASS groups fell within this range, suggesting that the participants in both groups were adequately treated. We therefore attribute the lack of statistical significance to the overall low incidence of dislocation in both groups.

In addition to its association with more consistent cup positioning in our cohort, HIP COMPASS offers several practical advantages over digital navigation systems. First, as an analog device, it carries a lower risk of unexpected errors or malfunctions than digital systems. Second, whereas CT-based and imageless navigation systems are typically compatible only with specific implant manufacturers, HIP COMPASS may, in principle, be applicable across different manufacturers and implant models, as long as the direction of cup-holder fixation corresponds to the apex of the acetabular component. Finally, it is cost-effective, requiring only two Kirschner wires per surgery.

However, HIP COMPASS also has the disadvantage that it can only be used with the supine surgical approach. Suzuki *et al.* [37] reported that insertion angle error tends to be larger in obese cases, particularly those with a soft tissue thickness of ≥ 37.2 mm at

the PS on preoperative CT images. Therefore, although HIP COMPASS may not be appropriate in cases requiring a lateral approach or in those with severe obesity, it remains a useful and practical tool for routine use.

In previous reports, the dislocation rates associated with CT-based navigation and robotic-assisted total hip arthroplasty were both approximately 0.5% [1,27,38,39], whereas imageless navigation has been reported to have a dislocation rate of approximately 1.0% [22,40]. The dislocation rate observed in the HIP COMPASS group in the present study can thus be considered comparable to that reported for imageless navigation.

With regard to placement accuracy, CT-based navigation and robotic-assisted systems have been reported to achieve mean errors of approximately 2° for inclination and 1° for anteversion, whereas imageless navigation systems have shown mean errors of approximately 3° for both inclination and anteversion [22,23]. These values are comparable to the placement accuracy previously reported for HIP COMPASS [11,13]. Taken together, HIP COMPASS may not achieve the same level of accuracy as CT-based navigation or robotic-assisted systems; however, its reported placement accuracy appears comparable to that of imageless navigation. Moreover, differences in dislocation rates are difficult to interpret given the low even count in our cohort.

As mentioned above, HIP COMPASS can only be used with a supine approach, whereas imageless navigation systems are applicable in the lateral decubitus position as well. However, in institutions where THA is routinely performed exclusively in the supine position and where substantial capital investment in navigation or robotic systems is difficult, HIP COMPASS may represent a practical alternative option.

This study has several limitations. First, in addition to the technical constraints of HIP COMPASS, the retrospective nature of the study may have introduced selection bias and residual confounding, limiting the ability to draw definitive causal inferences. Second, although the sample size was sufficient to evaluate the primary outcome, namely, revision-free implant survivorship of CoC THA using HIP COMPASS, it was underpowered to ascertain whether HIP COMPASS was associated with a reduced dislocation rate following THA. Further research with random allocation and a larger cohort is necessary to establish the superiority of HIP COMPASS. Third, although the follow-up duration exceeded 10 years and represents a major strength

of this study, longer-term follow-up beyond 20 years would be desirable to fully evaluate implant survivorship. Extended follow-up is required to evaluate long-term clinical outcomes and complications. Fourth, the follow-up period differed between the groups, which may have influenced the interpretation of revision outcomes. Although Kaplan–Meier analysis was used to account for differences in follow-up duration, this imbalance remains a potential limitation of the study. Finally, in the evaluation of component placement accuracy, the deviation from the preoperative plan would ideally have been assessed. However, because the preoperative planning data were unavailable in some cases, placement accuracy was instead evaluated using the Lewinnek safe zone. This represents one of the limitations of the present study.

In conclusion, these findings suggest that HIP COMPASS may be a viable intraoperative guidance option for surgeons, given its broad compatibility with acetabular components and low cost.

Acknowledgments. We would like to thank Editage (www.editage.jp) for English language editing. Subsequent substantive revisions and final editing were performed by KN International, Inc. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Sugano N, Takao M, Sakai T, Nishii T and Miki H: Does CT-based navigation improve the long-term survival in ceramic-on-ceramic THA? *Clin Orthop Relat Res* (2012) 470: 3054–3059.
2. Morrey BF: Difficult complications after hip joint replacement: dislocation. *Clin Orthop Relat Res* (1997) 344: 179–187.
3. Widmer KH and Zurfluh B: Compliant positioning of total hip components for optimal range of motion. *J Orthop Res* (2004) 22: 815–821.
4. Shon WY, Baldini T, Peterson MG, Wright TM and Salvati EA: Impingement in total hip arthroplasty a study of retrieved acetabular components. *J Arthroplasty* (2005) 20: 427–435.
5. Wroblewski BM, Siney PD and Fleming PA: Effect of reduced diameter neck stem on incidence of radiographic cup loosening and revisions in Charnley low-frictional torque arthroplasty. *J Arthroplasty* (2009) 24: 10–14.
6. Langton DJ, Jameson SS, Joyce TJ, Webb J and Nargol AVF: The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. *J Bone Joint Surg Br* (2008) 90: 1143–1151.
7. Barrack RL, Burak C and Skinner HB: Concerns about ceramics in THA. *Clin Orthop Relat Res* (2004) 429: 73–79.
8. Furmanski J, Anderson M, Bal S, Greenwald AS, Halley D, Penenberg B, Ries M and Pruitt L: Clinical fracture of cross-linked UHMWPE acetabular liners. *Biomaterials* (2009) 30: 5572–5582.
9. Japanese Society for Replacement Arthroplasty. Japanese Total

- Hip Arthroplasty Registry: Annual Report 2023. Tokyo: JSRA; 2024.
10. Migliorini F, Cuozzo F, Oliva F, Eschweiler J, Hildebrand F and Maffulli N: CT-based navigation for total hip arthroplasty: a meta-analysis. *Eur J Med Res* (2023) 28: 443.
 11. Suda K, Ito T, Miyasaka D, Imai N, Minato I and Endo N: Cup implantation accuracy using the HipCOMPASS mechanical intra-operative support device. *Springerplus* (2016) 5: 784.
 12. Murray DW: The definition and measurement of acetabular orientation. *J Bone Joint Surg Br* (1993) 75: 228–232.
 13. Imai N, Takubo R, Suzuki H, Shimada H, Miyasaka D, Tsuchiya K and Endo N: Accuracy of acetabular cup placement using CT-based navigation in total hip arthroplasty: comparison between obese and non-obese patients. *J Orthop Sci* (2019) 24: 482–487.
 14. Nozaki A, Imai N, Funayama K, Horigome Y, Suzuki H, Minato I, Kobayashi K and Kawashima H: Accuracy of ZedView, the software for three-dimensional measurement and preoperative planning: a basic study. *Medicina (Kaunas)* (2023) 59: 1030.
 15. Habe Y, Hamada H, Uemura K, Takashima K, Ando W and Sugano N: Cup safe zone and optimal stem anteversion in total hip arthroplasty for patients with highly required range of motion. *J Orthop Res* (2024) 42: 1283–1291.
 16. Widmer KH: The impingement-free, prosthesis-specific, and anatomy-adjusted combined target zone for component positioning in THA depends on design and implantation parameters of both components. *Clin Orthop Relat Res* (2020) 478: 1904–1918.
 17. Lewinnek GE, Lewis JL, Tarr R, Compere CL and Zimmerman JR: Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* (1978) 60: 217–220.
 18. Nakahara I, Takao M, Sakai T, Nishii T, Yoshikawa H and Sugano N: Gender differences in 3D morphology and bony impingement of human hips. *J Orthop Res* (2011) 29: 333–339.
 19. Cook SD, Thomas KA, Dalton JE, Volkman TK, Whitecloud 3rd TS and Kay JF: Hydroxylapatite coating of porous implants improves bone ingrowth and interface attachment strength. *J Biomed Mater Res* (1992) 26: 989–1001.
 20. Jasty M, Bragdon C, Burke D, O'Connor D, Lowenstein J and Harris WH: In vivo skeletal responses to porous-surfaced implants subjected to small induced motions. *J Bone Joint Surg Am* (1977) 79: 707–714.
 21. Phillips CB, Barrett JA, Losina E, Mahomed NN, Lingard EA, Guadagnoli E, Baron JA, Harris WH, Poss R and Katz JN: Incidence rates of dislocation, pulmonary embolism, and deep infection during the first six months after elective total hip replacement. *J Bone Joint Surg Am* (2003) 85: 20–26.
 22. Ohya Y, Sugama R, Kim Y, Ohta Y, Minoda Y and Nakamura H: A new accelerometer-based portable navigation system provides high accuracy of acetabular cup placement in total hip arthroplasty in both the lateral decubitus and supine positions. *Arch Orthop Trauma Surg* (2023) 143: 4473–4480.
 23. Hasegawa M, Naito Y, Tone S, Wakabayashi H and Sudo A: Accuracy of acetabular cup insertion in an anterolateral supine approach using an accelerometer-based portable navigation system. *J Artif Organs* (2021) 24: 82–89.
 24. Ogawa H, Kurosaka K, Sato A, Hirasawa N, Matsubara M and Tsukada S: Does an augmented reality-based portable navigation system improve the accuracy of acetabular component orientation during THA? a randomized controlled trial. *Clin Orthop Relat Res* (2020) 478: 935–943.
 25. Paprosky WG and Muir JM: Intellijoint HIP®: a 3D mini-optical navigation tool for improving intraoperative accuracy during total hip arthroplasty. *Med Devices (Auckl)* (2016) 9: 401–408.
 26. Steppacher SD, Kowal JH and Murphy SB: Improving cup positioning using a mechanical navigation instrument. *Clin Orthop Relat Res* (2011) 469: 423–428.
 27. Imai N, Miyasaka D, Ibuchi S, Kimura K, Hirano Y, Horigome Y and Kawashima H: The long-term efficacy of computed tomography-navigated total hip arthroplasty: an 18-year follow-up study. *J Clin Med* (2024) 13: 1374.
 28. Walter WL, Insley GM, Walter WK and Tuke MA: Edge loading in third-generation alumina ceramic-on-ceramic bearings: stripe wear. *J Arthroplasty* (2004) 19: 402–413.
 29. Poggie RA, Turgeon TR and Coutts RD: Failure analysis of a ceramic bearing acetabular component. *J Bone Joint Surg Am* (2007) 89: 367–375.
 30. Hannouche D, Zaoui A, Zadegan F, Sedel L and Nizard R: Thirty years of experience with alumina-on-alumina bearings in total hip arthroplasty. *Int Orthop* (2011) 35: 207–213.
 31. Kunutsor SK, Barrett MC, Beswick AD, Judge A, Blom AW and Wylde V: Risk factors for dislocation after primary total hip replacement: meta-analysis of 125 studies involving approximately five million hip replacements. *Lancet Rheumatol* (2019) 1: e111–e121.
 32. Bistolfi A, Crova M, Rosso F, Titolo P, Ventura S and Massazza G: Dislocation rate after hip arthroplasty within the first postoperative year: 36mm versus 28mm femoral heads. *Hip Inter* (2011) 21: 559–564.
 33. Mallory TH, Lombardi AV Jr, Fada RA, Herrington SM and Eberle RW: Dislocation after total hip arthroplasty using the anterolateral abductor split approach. *Clin Orthop Relat Res* (1999) 358: 166–172.
 34. Kwon MS, Kuskowski M, Mulhall KJ, Macaulay W, Brown TE and Saleh KJ: Does surgical approach affect total hip arthroplasty dislocation rates? *Clin Orthop Relat Res* (2006) 447: 34–38.
 35. Sheth D, Cafri G, Inacio MCS, Paxton EW and Namba RS: Anterior and anterolateral approaches for total hip arthroplasty are associated with lower dislocation risk without higher revision risk. *Clin Orthop Relat Res* (2015) 473: 3401–3408.
 36. Masonis JL and Bourne RB: Surgical approach, abductor function, and total hip arthroplasty dislocation. *Clin Orthop Relat Res* (2002) 405: 46–53.
 37. Suzuki H, Imai N, Hirano Y and Endo N: Accuracy of acetabular cup implantation, as a function of body mass index and soft-tissue thickness, with a mechanical intraoperative support device: a retrospective observational study. *Acta Med Okayama* (2021) 75: 575–583.
 38. Ilgen RL Nd, Bukowski BR, Abiola R, Anderson P, Chughtai M, Khlopas A and Mont MA: Robotic-assisted total hip arthroplasty: outcomes at minimum two-year follow-up. *Surg Technol Int* (2017) 30: 365–372.
 39. Kayani B, Konan S, Ayuob A, Ayyad S and Haddad FS: The current role of robotics in total hip arthroplasty. *EFORT Open Rev* (2019) 4: 618–625.
 40. Migliorini F, Cuozzo F, Oliva F, Eschweiler J, Hildebrand F and Maffulli N: Imageless navigation for primary total hip arthroplasty: a meta-analysis study. *J Orthop Traumatol* (2022) 23: 21.