



Original article

Isolated acetabular revision with femoral stem retention using computed tomography-based navigation

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ABSTRACT

Background: In isolated acetabular revision surgery, surgeons must place the cup at an appropriate angle with various retained stem anteversion angles to prevent postoperative dislocation. For accurate acetabular cup position, various navigation systems have been used. Nevertheless, no publications have reported combined cup and stem anteversion and dislocation rates after isolated acetabular revision, especially comparing the use of navigation with manual implantation. Therefore we performed a retrospective comparative study to answer the following questions: (1) What is the combined anteversion after isolated acetabular revision with computed tomography-based navigation? (2) Does navigation improve the accuracy of cup angle and combined anteversion, (3) reduce dislocation rate, and (4) reduce operative time?

Hypothesis: A navigation system makes combined anteversion near the target angle in isolated acetabular revision.

Patients and methods: We conducted a retrospective study of 32 hips in 24 patients who underwent isolated acetabular revision total hip arthroplasty using computed tomography-based navigation system. The control group comprised 8 hips in 8 patients who underwent the same procedure without navigation.

Results: In the navigation group, average Widmer's combined anteversion was $39.0^\circ \pm 8.7^\circ$ (range, 25.3° – 56.6°). Cup positions were $40.3^\circ \pm 2.9^\circ$ (range, 29.0° – 49.0°) for radiographic abduction angle, $24.3^\circ \pm 8.0^\circ$ (range, 4.6° – 42.6°) for radiographic anteversion. In the control group, Widmer's combined anteversion was $47.2^\circ \pm 15.1^\circ$ (range, 27.0° – 74.3° , $p=0.048$). The average cup positions for radiographic abduction angle and anteversion were $36.7^\circ \pm 8.9^\circ$ (range, 24.5° – 54.9°) and $29.1^\circ \pm 7.3^\circ$ (range, 17.2° – 38.8°), respectively ($p > 0.05$). Widmer's combined anteversion deviated from the target angle by a smaller amount in the navigation group than in the control group: errors in measurement of Widmer's combined anteversion were $7.2^\circ \pm 5.1^\circ$ (range, 0.74° – 19.6°) in the navigation group and $13.9^\circ \pm 11.1^\circ$ (range, 3.6° – 37.3°) in the control group ($p=0.135$). Postoperative dislocation occurred in none of the 32 hips (0%) in the navigation group and in one of the 8 hips (12.5%) in the control group ($p=0.2$).

Discussion: Using the navigation system, combined anteversion is made near the target angle in isolated acetabular revision surgery and more accurately than manual implantation. These results should be considered as preliminary since this is a limited cohort, but it brings new knowledge in navigation considering the very limited number of series using of navigation in isolated cup revision of total hip arthroplasty. In addition this is the first study to investigate combined cup and stem anteversion in isolated acetabular revision. The use of CT-scan is helpful to diagnose error in stem anteversion and to adapt the orientation of the new cup.

Level of evidence: III, Retrospective case control study.

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1. Introduction

In total hip arthroplasty (THA), osteolysis and aseptic loosening often occur earlier around the acetabular component than around the femoral component [1,2]. In revision surgery, replacement of a well-fixed stem implant presents risks, including femoral fracture and increased blood loss, operative time, and bone loss. In cases with only isolated component loosening, replacement of the loosened component is recommended and less invasive [3], but the disadvantages include a limited operative field and difficulty adjusting the soft tissue tension, readjusting the anteversion and lateral offset, controlling leg length discrepancy. Thus, the dislocation rate after revision surgery is higher than that after primary surgery [4]. To achieve optimal range of motion and prevent dislocation, Widmer et al. [5] proposed measuring “combined anteversion”. A malpositioned acetabular cup leads to a narrow range of motion, high dislocation rate, polyethylene wear, and low survival rate [6,7]. Consequently, in revision surgery, more accurate component implantation is needed than in primary surgery.

There are various reports concluding that navigation systems improve the accuracy of implant position [8,9]. Revision surgery often causes severe bone loss; therefore, preoperative segmentation and intraoperative registration require special attention when computed tomography (CT)-based navigation is used. Metal artifacts and bone atrophy obstruct CT imaging and surface registration; hence, CT-based navigation may not achieve the same accuracy in revision surgery as in primary surgery. A few studies [10,11] have shown that using CT-based navigation achieves the same accuracy for both primary and revision surgery. This is the first study to investigate combined cup and stem anteversion in isolated acetabular revision and to compare isolated acetabular revision THA with and without navigation.

The following questions arise:

- what is the combined anteversion after isolated acetabular revision with CT-based navigation?;
- does navigation improve the accuracy of cup angle and combined anteversion;
- reduce dislocation rate;
- reduce operative time?

We hypothesize that a navigation system makes combined anteversion near the target angle in isolated acetabular revision.

2. Patients and methods

2.1. Patients

The institutional review board at Oita University approved this retrospective study (approval number: 1414). All participants provided informed consent at the follow-up examination. These surgeries were performed by one surgeon (NK) using the posterolateral approach, and only the acetabular component was replaced. After patient selection (Fig. 1), we retrospectively reviewed 40 consecutive isolated acetabular revision surgeries performed from January 2006 to August 2018 and follow-up until December 2018. We reviewed 32 hips that underwent isolated acetabular revision using a CT-based 2D-3D fluoroscopic matched navigation (VectorVision Compact Hip CT version 3.5.2; BrainLab, Munich, Germany), between February 2010 and August 2018. Postoperative follow-up period was > 2 years in 22 of 32 hips. The control group consisted of 8 hips that underwent the same procedure without navigation between January 2006 and January 2010. The indication for revision surgery was cup loosening. Patient demographic data is shown in Table 1.

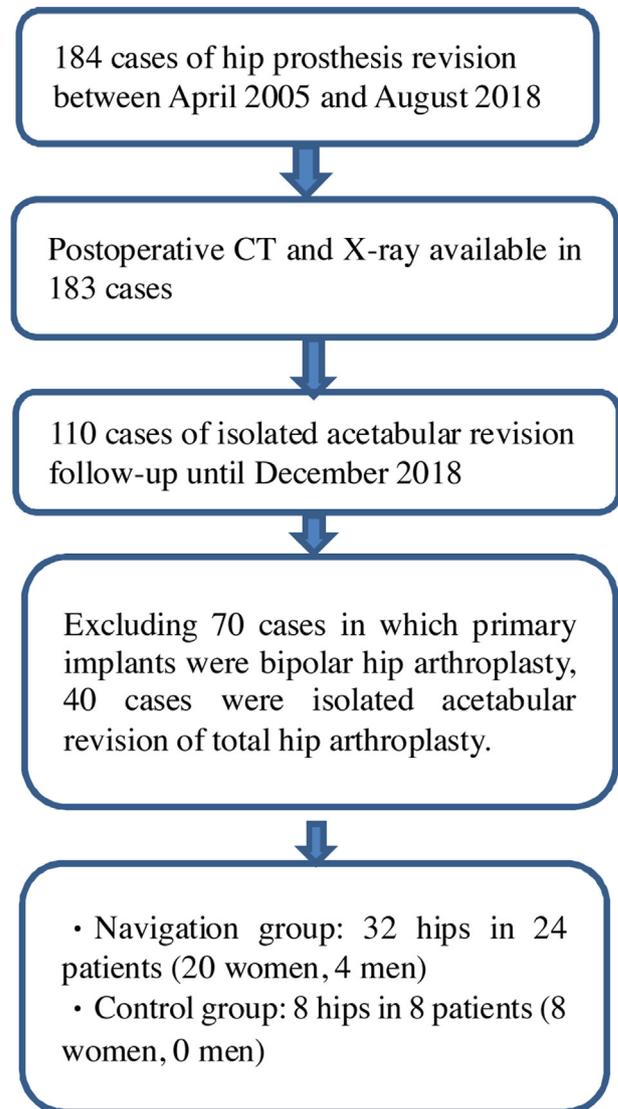


Fig. 1. Flow chart of the study patient.

The cups used are listed in Table 2. Our hospital performs many THA revisions for patients with various original implants. The replacement implants need to be compatible with the inserted femoral implant and the navigation bar needs to be attachable to the cup insertion handle. AAOS classification of the hips in our study was as follows. Navigation group (n): Type I: 17, Type II: 2, Type III: 13, Type IV: 0. Control group (n): Type I: 5, Type II: 0, Type III: 3, Type IV: 0. We evaluated operative time, bleeding, cup and stem angles, combined anteversion, postoperative dislocation, and re-revision rate.

2.2. Methods

2.2.1. Preoperative planning

CT images from the iliac wing to the knee joint were acquired using a helical CT scanner (Aquilion CX; Toshiba Medical Systems Corporation, Tokyo, Japan) with 1-mm slice thickness. CT data were transferred to the planning module and used to determine the optimal component size, angle, and position. We aimed to implant the acetabular component with radiographic combined anteversion of the cup and femoral stem of 37° using Widmer’s equation [cup anteversion + (0.7 × stem anteversion)] [11] and radiographic abduction angle of 40°.

Table 1
Patient demographics.

	Navigation group (n = 32)	Control group (n = 8)	p value
Age (years)	68.1 ± 11.1 (range, 36–87)	52.5 ± 12.9 (range, 32–69)	p = 0.001
Sex (male/female)	4/28	0/8	p = 0.623
Body mass index (kg/m ²) BMI > 30	25.7 ± 3.9 (range, 17.9–33.2) 5 cases (15.6%)	24.1 ± 1.8 (range, 20.7–26.1) 0 case (0%)	p = 0.107
Bleeding (mL)	382 ± 232 (range, 70–1100)	513 ± 444 (range, 30–1235)	p = 0.443
Operative time (min)	228 ± 76 (range, 149–553)	248 ± 95 (range, 185–285)	p = 0.066
Observation period (months)	49 ± 34 (range, 7–106)	136 ± 15 (range, 109–155)	p < 0.001
Head size (mean ± SD in mm) and number	31.5 ± 2.628 mm: 832 mm: 2136 mm: 240 mm: 1	29.5 ± 2.1 28 mm: 4 32 mm: 4	p = 0.038

Table 2
Product name and case number.

Cup	Navigation group (n = 32)	Control group (n = 8)
K-MAX KT plate S + Standard Socket CP (JMM, Kyoto, Japan)	15	–
K-MAX KT plate S + Crossfire Polyethylene (Stryker, Kalamazoo, MI, USA)	–	3
SQRUM TT (KYOCERA, Kyoto, Japan)	6	–
AMS HA Shell (JMM)	3	1
Continuum Acetabular System (Zimmer, Warsaw, IN, USA)	1	–
REFLECTION SPM (Smith and Nephew, Inc, Memphis, TN)	1	–
G7 (Zimmer)	3	–
Trabecular Metal Cup (Zimmer)	2	–
Tritanium Acetabular System (Stryker)	1	–
Mallory Head Radial Shell (Biomet, Warsaw, IN, USA)	–	2
TriAD HA PSL (Stryker)	–	2

2.2.2. Intraoperative procedures: Navigation group

We performed a two-stage operation. During the first stage, after surgical hand washing and surgical drape, we set navigation and surface registration. The second stage begins with surgical hand washing and surgical drape again. First stage was usually 15–20 min. Operative time was measured from the second stage onwards. We set patients in a lateral position with both ischial tuberosities perpendicular to the ground. Then, we inserted two screws and placed the antenna on the iliac crest. Two fluoroscopic pelvic images, recorded from different angles of > 20°, were obtained using a mobile fluoroscopy system (Philips BV-29 C-Arm; Koninklijke Philips N.V, Eindhoven, the Netherlands). Surface matching was performed by touching the superior iliac spine and iliac crest. The pubic symphysis position was finely adjusted and calibrated within 2 mm. When we reamed the acetabular side and inserted the acetabular implant, we attached the navigation bar to the handle. While reaming, we checked the real-time acetabular cup angle on monitor.

2.2.3. Intraoperative procedures: control group

We measured the installed stem angles via CT before surgery. The patient's pelvis was set exactly vertical on the operating table. Before the implants were removed, we marked their angle line on the pelvis using a surgical sheet. Considering these landmarks, we determined the cup installation angle and placed the new cup using the common alignment guide attached to the cup and landmarks.

2.3. Postoperative assessment

Postoperative cup angles were measured on postoperative X-rays using the planning module (2D-template, KYOCERA, Kyoto, Japan). Femoral stem anteversion was defined, using CT, as the angle formed between the proximal femoral stem axis and a line tangential to the bilateral posterior femoral condylar margin on the axial plane. All measurements were performed three times by three orthopedic surgeons and averaged.

2.4. Statistical analysis

There was no missing data in this study. Statistical analyses were performed using SPSS version 22 (IBM Corp., Armonk, NY, USA). Independent samples were first analyzed using Levine's test to check variance. Unpaired *t*-tests were used to compare demographic data such as age, body mass index, bleeding, operative time, observation period, head size, mean radiographic abduction/anteversion, stem anteversion, combined anteversion and Error of Widmer's combined anteversion. Fisher's exact test was used to analyze dislocation rate and sex. *p* < 0.05 indicated statistical significance in all analyses.

3. Results

Without age, observation period and head size, the evaluated background parameters did not differ significantly (Table 1). In the navigation group, combined anteversion was 39.0° ± 8.7° (range 25.3°–56.6°) and errors in the measurement of Widmer's combined anteversion were 7.2° ± 5.1° (range 0.74°–19.6°). Nine of 32 hips (28.1%) were within the safe zone of Widmer (37 ± 3°). In the navigation group, the mean radiographic abduction and radiographic anteversion were 40.3° ± 2.9° (range 29.0°–49.0°) and 24.3° ± 8.0° (range 4.6°–42.6°). In the control group, the mean radiographic abduction, radiographic anteversion, combined anteversion and errors in the measurement of Widmer's combined anteversion were 36.7° ± 8.9° (range 24.5°–54.9°), 29.1° ± 7.3° (range 17.2°–38.8°), 47.2° ± 15.1° (range 27.0°–74.3°) and 13.9° ± 11.1° (range 3.6°–37.3°), respectively. For these angles, there was no significant difference between the two groups. In the control group, none of the 8 hips (0%) were within the safe zone of Widmer. Between the navigation and control groups, there was no difference in the deviation (Figs. 2–4). Nevertheless, Widmer's combined anteversion deviation from the target angle in the navigation group tended to be smaller than that in the control group (*p* = 0.135; Figs. 5 and 6).

There were no intraoperative complications. Postoperative complications included one case of deep infection in the navigation group. Postoperative dislocation occurred in none of the 32 hips (0%) in the navigation group and one of the 8 hips (12.5%) in

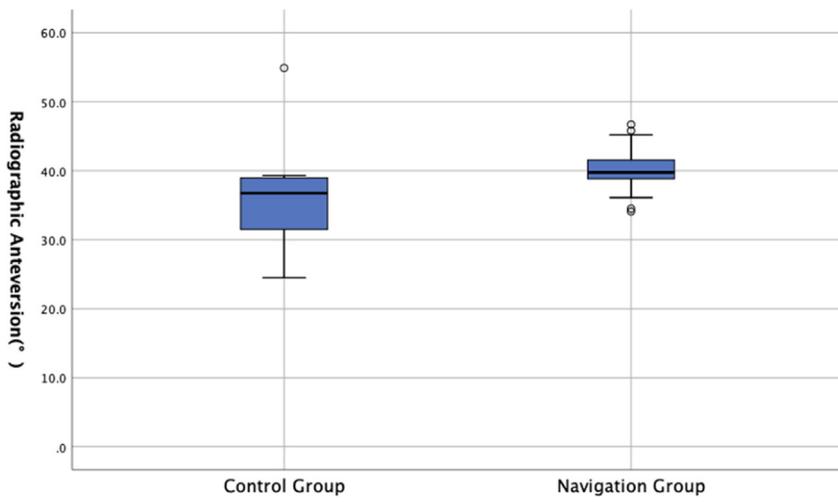


Fig. 2. Box-and-whisker plot of radiographic anteversion showing similar deviations.

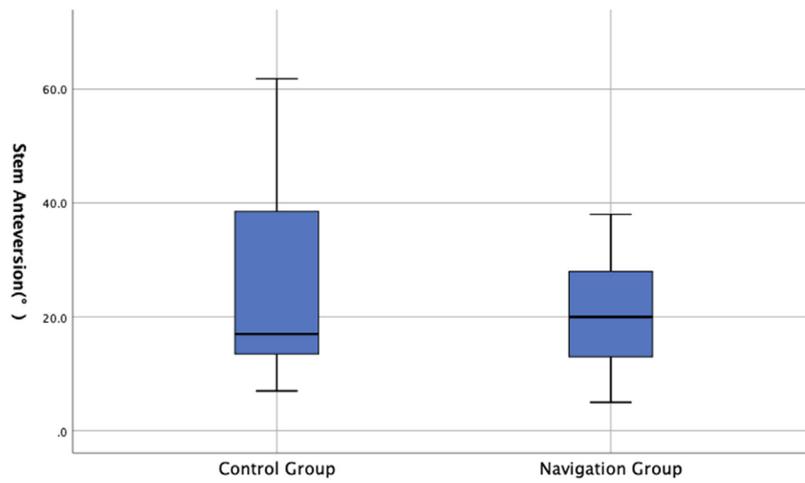


Fig. 3. Box-and-whisker plot of stem anteversion showing similar deviations.

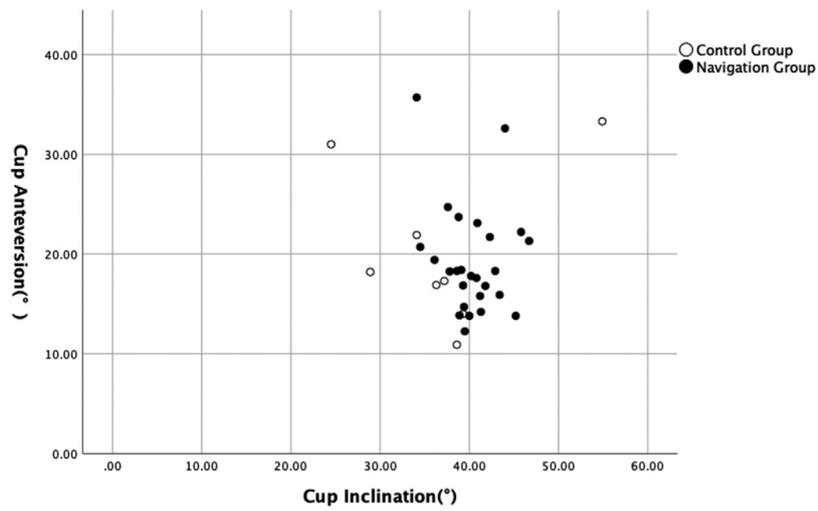


Fig. 4. Scatter plots of inclination and anteversion of the cup.

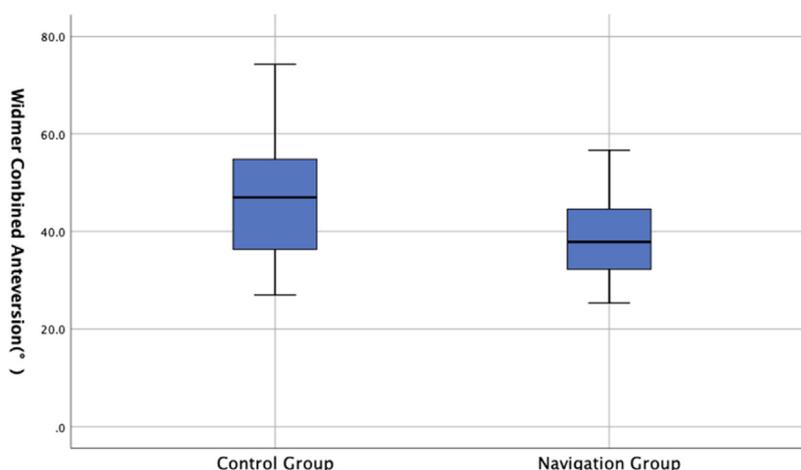


Fig. 5. Box-and-whisker plot of Widmer's combined anteversion. Deviation from the target angle is significantly less in the navigation group than in the control group.

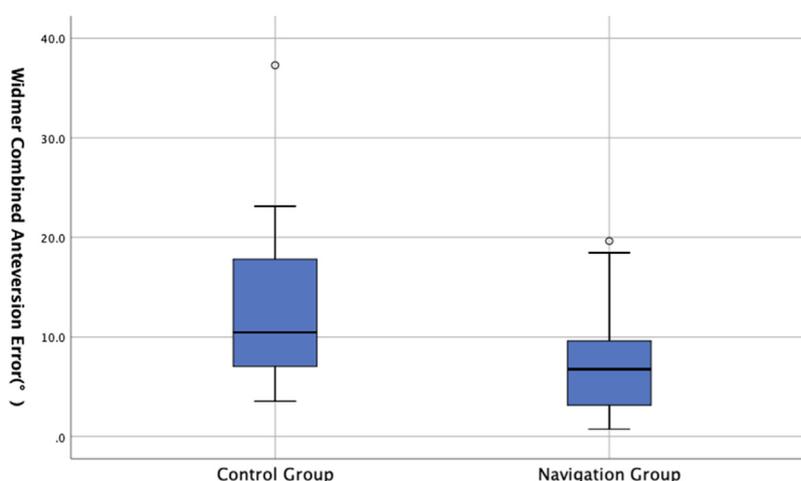


Fig. 6. Box-and-whisker plot of the error of Widmer's combined anteversion; 75% of the navigation group is within $37^\circ \pm 10^\circ$, and 50% of the control group is within $37^\circ \pm 10^\circ$.

Table 3

Previous reports on isolated acetabular revision with manual implantation.

	Observation period (months, range)	Cases (n)	Accuracy		Dislocation	Re-revision
			Radiographic abduction angle	Radiographic anteversion		
Manning et al. [14]	28 (25–32)	26	$48.9^\circ \pm 5.9^\circ$	$25.6^\circ \pm 4.5^\circ$	0	–
Elke et al. [15]	88.8 (60–126)	123	$37^\circ (29^\circ\text{--}48^\circ)$	$7^\circ (3^\circ\text{--}15^\circ)$	9 (7.3%)	13 (10.6%)
He et al. [16]	56.4 (24–111.6)	36	$43.6^\circ (32^\circ\text{--}57^\circ)$	–	1 (2.8%)	0
Kim et al. [17]	76 (37–131)	43	48°	18°	2 (4.7%)	5 (11.6%)
Cogan et al. [18]	28.8 (12–84)	61	Dislocated (n=4) $39.5^\circ \pm 4^\circ$ Non-dislocated (n=57) $44.5^\circ \pm 5.5^\circ$	$25.6^\circ \pm 11.5^\circ$ $18.9^\circ \pm 9^\circ$	4 (6.6%)	–

the control group ($p=0.2$). The dislocation occurred due to a fall; it was not repeated. There was no re-revision in either group.

4. Discussion

Manual isolated acetabular revision has been reported with a relatively higher dislocation rate (0–20%) [3,12–18]. Although reports [14–18] have discussed the acetabular implant angle with manual implantation, they reported a relatively wide standard deviation (Table 3). However, the combined cup and stem anteversion after isolated acetabular revision remains unclear. Chang et al. [19] reported that Widmer's combined anteversion of 40 revision THA hips was $36.1^\circ \pm 3.4^\circ$ (range $27.2^\circ\text{--}42.9^\circ$). Their “safe zone” of combined anteversion was $37^\circ \pm 10^\circ$ and all their revision cases

were within the zone (100%). In our study, combined anteversion was $39.0^\circ \pm 8.7^\circ$ (range $25.3^\circ\text{--}56.6^\circ$) and 25 of 32 hips (78.1%) were within their safe zone. Errors in Widmer's combined anteversion measurement were $7.2^\circ \pm 5.1^\circ$ (range $0.74^\circ\text{--}19.6^\circ$). The difference of achievement rate between their study and ours may due to our cases being all isolated acetabular revision.

The navigation system is a support tool for improving the accuracy of cup positioning. Sugano et al. [20] reported the accuracy of CT-based navigation cases of primary total hip arthroplasty compared with that of freehand cases; the dislocation rate was 8.75% (7/80) in freehand cases and 0% in CT-based navigation cases. They showed that primary surgery using CT-based navigation leads to not only accurate cup position but also long-term implant survival rate. We used the same navigation system and settings as Yamada

Table 4
Isolated acetabular revision in our study.

	Navigation group Mean \pm SD (n = 32)	Control group Mean \pm SD (n = 8)	p value
Radiographic abduction angle	40.3° \pm 2.9° (range, 29.0°–49.0°)	36.7° \pm 8.9° (range, 24.5°–54.9°)	p = 0.305
Radiographic anteversion	24.3° \pm 8.0° (range, 4.6°–42.6°)	29.1° \pm 7.3° (range, 17.2°–38.8°)	p = 0.137
Widmer's combined anteversion	39.0° \pm 8.7° (range, 25.3°–56.6°)	47.2° \pm 15.1° (range, 27.0°–74.3°)	p = 0.048
Stem anteversion	20.9° \pm 9.1° (range, 5.2°–37.8°)	25.9° \pm 18.7° (range, 7.0°–61.8°)	p = 0.487
Error of Widmer's combined anteversion	7.2° \pm 5.1° (range, 0.74°–19.6°)	13.9° \pm 11.1° (range, 3.6°–37.3°)	p = 0.135

SD: Standard deviation.

et al. [21], who have reported that accuracy between intraoperative navigation angle and postoperative CT angle of cup inclination was $2.5^\circ \pm 2.2^\circ$ and cup anteversion was $2.3^\circ \pm 1.7^\circ$. Therefore, our intraoperative navigation angle was reliable. Knowing the stem anteversion via CT imaging, the appropriate cup anteversion for the combined anteversion theory can be decided preoperatively. Nevertheless, it is difficult to achieve manually because surgeons have to set up the same operative angle based on the table plane. We found that Widmer's combined anteversion was improved in the navigation group compared to the control group significantly but radiographic anteversion, inclination, and stem anteversion accuracy was not significantly different (Table 4, Figs 2–4). All evaluation factors for accuracy improved in the navigation group compared to the control group. Recent investigation by Reina et al. [22] has demonstrated that the acetabular cup, 40° – 50° inclination, and 15° – 30° anteversion target zone was better to prevent dislocation. Rivière et al. [23] recommend that cup positioning be switched to a patient-specific approach considering pelvic kinematics. Target zone is changeable as times change. Navigation system is useful for achieving the above, especially in acetabular revision.

According to Kuroda et al. [12] the postoperative dislocation rate of revision THA can be reduced to 6.67%, similar to that in primary THA, using CT-based navigation. We had no dislocations in the navigation group and one accident-related dislocation in the control group. However, we achieved good survival rates without re-revision at the mid-term follow-up for dislocation.

There was no significant difference in operative time between the groups, but the operative time tended to be longer in the control group. At our institute, operative time does not include the first stage. In revision surgery, it is difficult to identify the anatomy; hence, the surgeons hesitate over the acetabular implant angle. Navigation may, however, decrease the time spent in deciding the acetabular implant angle.

The limitations of the study should be considered, but do not jeopardize our overall conclusions. A randomized controlled trial was not performed. They are often infeasible for isolated acetabular revision. Few cases arise, rendering prospective study difficult; furthermore, withholding navigation assistance to create a simultaneous control group is likely to be unethical because of the benefits already shown [11,12]. The lack of simultaneity could mean the environment changed during the study and the shorter follow-up time in the navigation group could also disproportionately mask long-term complications. However, since follow-up exceeded 2 years in 22 of 32 navigation group hips, few complications would have come to light. We also had a small sample size, which is difficult to overcome in a small patient population. Further research is needed with additional clinical and radiological evaluation, such as Harris hip score, WOMAC score, and radiographic migration of the cup and radiolucent line.

5. Conclusion

We examined combined anteversion in isolated acetabular revision using a CT-based navigation and the accuracy of acetabular implant replacement using navigation compared with that using

manual implantation. Although isolated acetabular revision is a limited operative field, using a navigation system improved the accuracy of Widmer's combined anteversion with smaller deviations. Moreover, there was no dislocation in the navigation group. Nevertheless, further research is necessary to better support these findings.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contributions

Yuta Kubota contributed mainly to conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted, statistics, and surgery assistance. Nobuhiro Kaku contributed mainly to conception and design of the study, interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted, statistics, and surgery performance. Hiroaki Tagomori contributed mainly to acquisition of data, analysis of data, drafting the article, final approval of the version to be submitted, statistics, and surgery assistance. Masashi Kataoka contributed mainly to analysis of data, revising it critically for important intellectual content, final approval of the version to be submitted, statistics, and surgery assistance. Hiroshi Tsumura contributed mainly to interpretation of data, revising it critically for important intellectual content, final approval of the version to be submitted, statistics, and surgery assistance.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.otsr.2019.08.002>.

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