



# Does a computed tomography-based navigation system reduce the risk of dislocation after total hip arthroplasty in patients with osteonecrosis of the femoral head? A propensity score analysis

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Received: 1 May 2019 / Accepted: 5 February 2020 / Published online: 18 February 2020  
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## Abstract

This study aimed to investigate whether use of a computed tomography (CT)-based navigation system reduce the risk of dislocation after total hip arthroplasty (THA) in patients with osteonecrosis of the femoral head (ONFH). A total of 271 hips from 192 consecutive patients that underwent primary THA for ONFH were included. There were 110 hips in non-navigation group, and 161 hips in navigation group. After applying exclusion criteria, 209 hips from 149 patients were selected for analysis. Clinical outcomes and complication rates were evaluated, and implant alignments were also calculated. To identify whether the navigation system was useful to prevent dislocation, the inverse probability of treatment-weighted Cox regression analysis using a propensity score in relationship to sex, age at surgery, body mass index, and femoral head size was performed. No significant difference was observed in clinical scores between both groups. Dislocation was significantly lower in the navigation group (3 hips, 2.7%) than in the non-navigation group (11 hips, 11.2%;  $p=0.012$ ), whereas periprosthetic joint infection and aseptic loosening did not differ between the groups. Variance of cup inclination and anteversion angles was smaller in the navigation group than in the non-navigation group ( $p<0.001$ ). Use of the CT-based navigation system (hazard ratio; 0.26, 95% confidence interval, 0.07–0.98;  $p=0.047$ ) turned out to be the predictor for preventing dislocation. In conclusion, use of the CT-based navigation system provided a precise placement of components, and thus helps to prevent dislocation in patients with ONFH in the propensity score analysis.

**Keywords** Computed tomography-based navigation system · Osteonecrosis of the femoral head · Total hip arthroplasty · Propensity score analysis

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## Introduction

Osteonecrosis of the femoral head (ONFH) often causes severe pain due to femoral head collapse, which results in a significant reduction in the patient's daily activity. Total hip arthroplasty (THA) is one of the most effective treatments for relieving pain and restoring physical function in patients with ONFH [1]. Several studies prior to 1990 have shown that patients with ONFH who undergo THA have worse outcomes than patients with osteoarthritis (OA). This is because those with ONFH tend to be younger and more active, which are factors assumed to be related to higher dislocation and aseptic loosening rates observed in patients with ONFH [2, 3]. There have been many technological innovations in THA, including implant designs, liner materials, surgical techniques, and computer-assisted surgeries, and therefore, recent studies after 2000 have demonstrated good outcomes from THA, even for patients with ONFH [3–5]. Despite promising these results, a comprehensive analysis in the United States showed that mechanical complications and dislocation were increased in the ONFH group following THA after 2000 [6], and postoperative risk managements after THA in patients with ONFH are still controversial.

While there have been reports on one THA innovation—the usefulness of a computed tomography (CT)-based navigation system [7, 8]—there have been no reports that compared the clinical and radiological outcomes after THA performed with or without a CT-based navigation system in patients with ONFH. Thus, the advantages of a CT-navigation system remain unclear. Therefore, the purpose of this study is to investigate whether use of a CT-based navigation system reduce the risk of dislocation after THA in patients with ONFH.

## Materials and methods

This retrospective study was approved by the local ethics commission and all analyses were performed with permission from the Institutional Review Board of the authors' institution. Between January 1990 and December 2014, 271 hips from 192 consecutive patients who underwent primary THA for ONFH with a follow-up period of longer than 2 years (mean 10 years; range 2–26 years) were included in this study. Of the 271 hips, THA was performed without a CT-based navigation system in 110 hips between January 1990 and February 2004 (non-navigation group), whereas 161 hips underwent THA with a CT-based navigation system (CT-Hip System, Stryker, Freiburg, Germany) between March 2004 and December

2014 (navigation group). In the navigation group, preoperative CT images from the entire pelvis to the knee joint were taken and transferred into the preoperative planning module of the navigation system. The reference points (bilateral anterior superior iliac spines, bilateral pubic tubercles, the most distal point of bilateral ischium, mid pubic symphysis, and sacral mid-plane) were identified to create the pelvis coordinate system. A three-dimensional surface model of the pelvis was subsequently reconstructed using a segmentation procedure in the planning module. We defined the ideal cup orientation as 40° of radiographic inclination and 15° of radiographic anteversion, which took into consideration the range of motion without impingement during various daily activities and the avoidance of a high inclination angle to prevent the acetabular edge-loading when the mean average femoral anteversion was 30° [9].

All THAs were performed through a posterolateral approach in the non-navigation group. On the other hand, 143 THAs were performed through a posterolateral approach and 30 THAs were performed by an anterolateral approach in the navigation group. All operations were performed by four experienced hip surgeons in each group. Among a total of 271 hips in 192 patients, the following 62 hips were excluded from this study; 30 hips that underwent THA through an anterolateral approach, 19 hips that underwent osteotomy before the index THA, or 13 hips that underwent hip resurfacing or bipolar hip arthroplasty on the other side. In total, 209 hips (149 patients) were available for this study. Fifty-two hips of men and 46 hips of women were included in the non-navigation group; 49 hips of men and 62 hips of women were included in the navigation group. In the non-navigation group, ONFH was idiopathic in nine hips, associated with steroid therapy in 62 hips, and associated with alcohol abuse in 27 hips. In the navigation group, four hips were idiopathic, 87 hips were steroid-associated, and 20 hips were alcohol-associated. According to the Japanese Investigation Committee (JIC) classification [10], 34 hips were classified as stage 3A, 35 hips were in stage 3B, and 29 hips were in stage 4 in the non-navigation group, and there were 19 hips in stage 3A, 45 hips in stage 3B, and 47 hips in stage 4 in the navigation group. The average follow-up period in the non-navigation and navigation groups was 15 years (range 2–26 years) and 6 years (range 2–13 years), respectively (Table 1).

Table 2 shows details of implants in both groups. Cementless and hybrid THA was performed in 90 hips and eight hips in the non-navigation group, and 100 hips and 11 hips in the navigation group, respectively. All acetabular components were cementless fixation, and anatomical cementless stem was the most frequent in both groups; 57 hips (58.2%) in non-navigation group and 57 hips (51.4%) in navigation group. Concerning articulation,

**Table 1** Characteristics of patients

Variable	Non-navigation group (n = 98)	Navigation group (n = 111)	p Value
Age (years, mean ± SD)	47.5 ± 13.5	50.0 ± 16.1	0.184*
BMI (kg/m <sup>2</sup> , mean ± SD)	23.0 ± 3.6	22.4 ± 3.8	0.229 <sup>†</sup>
Male (hips)	52 (53.1%)	49 (44.1%)	0.220 <sup>‡</sup>
Associated factor of ONFH (hips)			0.038 <sup>§</sup>
Idiopathic	9 (9.2%)	4 (3.6%)	
Steroid	62 (63.3%)	87 (78.4%)	
Alcohol	27 (27.6%)	20 (18.0%)	
JIC stage (hips)			0.012 <sup>‡</sup>
3A	34 (34.7%)	19 (17.1%)	
3B	35 (35.7%)	45 (40.5%)	
4	29 (29.6%)	47 (42.3%)	
Follow-up period (years; mean, range)	15 (2–26)	6 (2–13)	<0.001*
Types of fixation (hips)			0.811 <sup>‡</sup>
Cementless	90 (91.8%)	100 (90.1%)	
Hybrid	8 (8.2%)	11 (9.9%)	
Types of articulation (hips)			<0.001 <sup>§</sup>
Metal on polyethylene	6 (6.1%)	21 (18.9%)	
Ceramic on polyethylene	40 (40.8%)	81 (73.0%)	
Ceramic on ceramic	33 (33.7%)	0 (0%)	
Metal on metal	19 (19.4%)	9 (8.1%)	
Femoral head size (hips)			<0.001 <sup>‡</sup>
≤ 32 mm	79 (80.6%)	40 (36.0%)	
≥ 36 mm	19 (19.4%)	71 (64.0%)	

SD standard deviation, BMI body mass index, ONFH osteonecrosis of the femoral head, JIC Japanese Investigation Committee

\*p Value calculated using Wilcoxon rank sum test; <sup>†</sup>p value calculated using Student's *t* test; <sup>‡</sup>p value calculated using Chi-square test; <sup>§</sup>p value calculated using Fisher's exact test

**Table 2** Details of implants in both groups

Variable	Non-navigation group (n = 98)	Navigation group (n = 111)
Cup (hips)		
Cementless	Spongiosa Metal, 33 (33.7%) AFJ, 22 (22.4%) Birmingham, 19 (19.4%) AMS, 11 (11.2%) Others, 13 (13.3%)	Trident, 96 (86.5%) ADEPT, 7 (6.3%) Trilogy, 3 (2.7%) Birmingham, 2 (1.8%) Others, 3 (2.7%)
Cemented		
Stem (hips)		
Cementless	Spongiosa Metal, 33 (33.7%) ANCA-FIT, 22 (22.4%) Freeman, 17 (17.3%) Perfix, 11 (11.2%) Others, 7 (7.1%)	CentPillar TMZF, 39 (35.1%) CentPillar GB, 16 (14.4%) Accolade TMZF, 15 (13.5%) Accolade II, 9 (8.1%) Others, 21 (18.9%)
Cemented	VerSys, 4 (4.1%) Others, 4 (4.1%)	DCMJ, 8 (7.2%) Others, 3 (2.7%)

there were six metal-on-polyethylene hips, 40 ceramic-on-polyethylene hips, 33 ceramic-on-ceramic hips, and 19 metal-on-metal hips in the non-navigation group. In the navigation group, there were 21 metal-on-polyethylene

hips, 81 ceramic-on-polyethylene hips, and 9 metal-on-metal hips in the navigation group. Of the 46 hips in the non-navigation group involving a polyethylene liner, a conventional polyethylene liner was used in 38 hips, and

a highly-cross-linked-polyethylene liner was used in eight hips. On the other hand, all 102 hips involving a polyethylene liner in the navigation group were highly cross-linked-polyethylene. Regarding femoral head size, a  $\leq 32$  mm and  $\geq 36$  mm femoral head diameter was used in 79 hips and 19 hips in the non-navigation group, and 40 hips and 71 hips in the navigation group, respectively (Table 1). All patients were allowed full weight-bearing in the immediate postoperative period, and they were encouraged and assisted to commence walking in both groups. In addition, physical therapists instructed patients to keep awareness of dislocation. Precaution was not used in the navigation group.

We assessed the clinical outcomes using the Japanese Orthopedic Association (JOA) score (0–100 points; best score, 100 points) [11]. Complications including dislocation, periprosthetic joint infection, and periprosthetic fracture were evaluated. To identify whether the navigation system was useful to prevent dislocation, the inverse probability of treatment-weighted (IPTW) Cox regression analysis using a propensity score in relationship to sex, age at surgery, body mass index (BMI), and femoral head size was performed.

We assessed the radiological outcomes. Anteroposterior (AP) and true lateral radiographs were taken preoperatively and at each annual follow-up. Femoral component migration was determined using the vertical distance from the shoulder of the stem to the midpoint of the lesser trochanter and the varus angle of the stem formed by the stem axis and the proximal femur axis. Greater than 4 mm subsidence vertically or a  $> 2^\circ$  change in the varus angle indicated stem migration and aseptic loosening [12]. Acetabular component loosening was defined as migration of  $> 2$  mm or change in the abduction angle of the acetabular component by  $> 5^\circ$  [13]. To measure the cup alignment, an ellipse was fitted to the rim of the acetabular component on the early postoperative AP radiographs using a computer software program (2D template, Kyocera Corporation, Kyoto, Japan) [7]. All radiographs were evaluated by one of the authors (KT) who was not a treating surgeon.

Kaplan–Meier survival analysis with revision as the end point was also performed. The investigation period was set to 6 years, which was the mean follow-up period of the navigation group.

### Statistical analysis

Continuous data were presented as mean  $\pm$  SD or median with minimum and maximum, and compared between navigation and non-navigation groups using Student's *t* test or Wilcoxon rank sum test as appropriate. Categorical data were presented as frequencies and percent, and analyzed by using the Chi-square test or Fisher's exact test as appropriate. Variance of both cup alignments was compared using *F* test. Cumulative survivals with revision as the end point were

estimated using the Kaplan–Meier method, and compared between the groups by the log-rank test. Due to the nature of the observational study, baseline imbalances between the groups could be existed; therefore, an adjusted analysis was performed using propensity score-based method. The propensity score for receiving navigation was calculated using multivariable logistic regression, and included sex, age at surgery, BMI, and femoral head size as variables. As the primary analysis, IPTW Cox proportional hazard regression analysis was used to compare survivals with revision and compute hazard ratio (HR) and its 95% confidence interval (CI). In addition, the Cox regression analysis including the propensity score as a covariate was also conducted to confirm robustness of the result from the IPTW Cox regression analysis. Results with *p* values of  $< 0.05$  were considered to be statistically significant differences. Statistical analysis was performed using JMP or SAS (SAS Institute, Cary, NC, USA) and R (<https://www.r-project.org/>).

### Results

No significant differences were observed in preoperative and postoperative JOA scores between both groups. Dislocation rates were significantly lower in the navigation group (3 hips, 2.7%) than in the non-navigation group (11 hips, 11.2%;  $p=0.012$ ), although periprosthetic joint infection and periprosthetic fracture did not differ between the groups (Table 3). Based on the results from the IPTW Cox regression analysis, use of the CT-based navigation system (HR; 0.26, 95% CI 0.07–0.98;  $p=0.047$ ) turned out to be the predictors for preventing dislocation. The other analyses which were to confirm robustness of the IPTW Cox regression analysis also showed that use of the CT-based navigation system reduced dislocation rates after THA in patients with ONFH (Table 4).

There was no aseptic loosening in the non-navigation group and one stem aseptic loosening in the navigation group. Cup loosening was not observed in either group. Mean cup inclination and anteversion angles in the non-navigation group were  $43.2^\circ \pm 5.7^\circ$  (range  $29.1^\circ$ – $53.5^\circ$ ) and  $15.5^\circ \pm 6.6^\circ$  (range  $0.6^\circ$ – $32.7^\circ$ ), respectively, and  $39.7^\circ \pm 3.0^\circ$  (range  $32.5^\circ$ – $47.3^\circ$ ) and  $14.0^\circ \pm 2.7^\circ$  (range  $6.5^\circ$ – $21.8^\circ$ ) in the navigation group, respectively. Those were significantly higher in the non-navigation group than in the navigation group (inclination,  $p=0.017$ ; anteversion,  $p<0.001$ ). Variance of both cup angles was smaller in the navigation group than in the non-navigation group (inclination,  $p<0.001$ ; anteversion,  $p<0.001$ ) (Fig. 1).

Two hips in each pair needed revision due to liner dislocation and periprosthetic joint infection in the non-navigation group, and stem aseptic loosening and periprosthetic joint infection in the navigation group. The survival rate with

**Table 3** Comparison of measurement items between both groups

Variable	Non-navigation group (n=98)	Navigation group (n=111)	p Value
JOA score (points, mean ± SD)			
Preoperative	46.8 ± 11.0	46.5 ± 14.0	0.760*
Postoperative	91.6 ± 9.6	92.2 ± 8.1	0.998*
Flexion angle (degree, mean ± SD)			
Preoperative	96.1 ± 17.7	87.4 ± 20.4	0.002*
Postoperative	107.2 ± 12.0	108.2 ± 11.1	0.674*
Abduction angle (degree, mean ± SD)			
Preoperative	19.5 ± 7.8	19.1 ± 8.8	0.617*
Postoperative	28.5 ± 5.0	28.8 ± 4.8	0.853*
Complications (hips)			
Dislocation	11 (11.2%)	3 (2.7%)	0.012 <sup>†</sup>
Periprosthetic joint infection	1 (1.0%)	1 (0.9%)	1 <sup>†</sup>
Periprosthetic fracture	0 (0%)	0 (0%)	NA

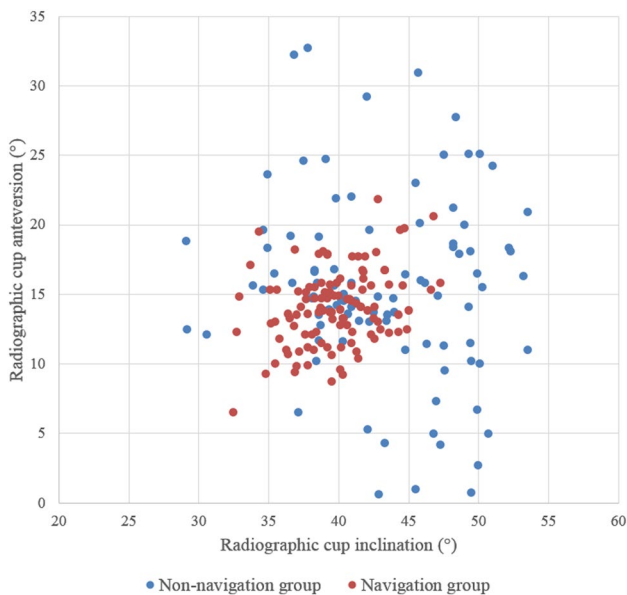
SD standard deviation, JOA Japanese Orthopedic Association, NA not applicable

\*p Value calculated using Wilcoxon rank sum test; <sup>†</sup>p value calculated using Fisher’s exact test

**Table 4** Cox regression analyses of relative risk of dislocation after THA using CT-based navigation system

Methods	Hazard ratio	95% Confidence interval	p Value
Non-adjusted	0.24	0.07–0.86	0.030
Adjusted			
IPTW	0.26	0.07–0.98	0.047
Propensity score as covariate	0.25	0.06–0.97	0.045

THA total hip arthroplasty, CT computed tomography, IPTW inverse probability of treatment weighted



**Fig. 1** Scattergram of the cup alignment plots of anteversion against inclination

revision as the end point at 6 years of follow-up in the non-navigation group was 97.8% (95% CI 94.7–100%), and that of the navigation group was 98.2% (95% CI 95.7–100%); no significant differences were observed between both groups ( $p=0.874$ ).

### Discussion

Although several studies reported the usefulness of CT-based navigation in THA [14], there have been no reports that compare the clinical outcomes and complications of THA performed with or without CT-based navigation in patients with ONFH. This study showed that use of the CT-based navigation system helps to prevent dislocation in patients with ONFH.

Computer-assisted surgery in THA has been used since the early 1990s, and includes computer-assisted preoperative planning, robotic devices, navigation, and patient-specific surgical guides [14]. Several studies have demonstrated that the use of a navigation system provided a more precise placement of components than conventional manual techniques, thus eliminating implant malpositioning and the risk of subsequent complications [7, 8]. Our results identified that the use of a CT-based navigation system provided precise implant placement and subsequently contributed to prevention of dislocation after THA for patients with ONFH. Soft-tissue balance may also influence on these results and further study is needed in the future.

With regard to implant design, a review article showed that using recently designed press-fit implants led to good THA outcomes in patients with ONFH [15]. Another study evaluated the outcome after THA in ONFH patients,

showing that revision rates of THA performed before 1990 (17%) were worse than those performed after 1990 (3%) [3]. In the present study, primarily anatomical cementless stems were used in the non-navigation group. Of those, the metal-cancellous cementless Lübeck prosthesis (Spongiosa Metal, S + G Implants, Lübeck, Germany) was the most frequently used (33 hips of 90 cementless THAs, 36.7%) in the non-navigation group. Several studies have reported that the prosthesis provided satisfactory clinical results and demonstrated good stability [16]. In addition, patients with sickle cell disease, whose prognosis is considered poor, are less frequent in Japan [3, 17]. This may have contributed to the low revision rates observed even in the non-navigation group.

Concerning articulation, patients with ONFH are more likely to be younger and more active than patients with OA, which might possibly correlate to high implant wear [3]. Ceramic-on-ceramic and highly-cross-linked polyethylene bearings have been reported to have a low wear rate, which is a beneficial outcome for patients with ONFH [4, 5]. Moreover, these new liner materials make it possible to use of large femoral heads. These bearing surfaces and the availability of large diameter femoral heads associated with decreased dislocation rates are the major technological innovations of modern THA [18]. In our results, no osteolysis associated with the typical wear was observed. In the future, long-term clinical studies will be required to clarify the factor(s) responsible for the articulation or femoral head size in patients with ONFH.

Many studies after 2000 demonstrated that marked improvement in the clinical outcomes, radiological outcomes, and survivorship of THA in patients with ONFH (Table 5) [4, 5, 19–21]. Mont et al. [19] reported the outcomes of cementless THA through an anterolateral approach in young adult patients with ONFH at a mean follow-up 3 years between January 2002 and January 2004. The mean Harris hip score (HHS) improved 30 points at preoperative to 92 points at postoperative, and the survivor rates with any revision as the end point were 96.1% for the ONFH group. The survivor rates were similar between the ONFH and OA groups (98%,  $p=0.575$ ). Kim et al. [20] evaluated 73 hips from 71 patients with ONFH younger than 50 years (mean age 45.5 years) who underwent cementless THA through a posterolateral approach with alumina on highly cross-linked polyethylene bearing from February 2000 to May 2002. The mean follow-up was 8.5 years, and the mean baseline HHS was 50.6 points, which improved to 96 points at final follow-up. Penetration rate of the polyethylene liner was below the osteolysis threshold, and no hip had aseptic loosening or osteolysis. Our results also showed the high survivorship of navigated THA in patients with ONFH, and clinical outcomes and complication rates were comparable with recent studies after 2000. According to the nationwide

**Table 5** Recent studies of outcomes for THA in patients with ONFH

Study	Year	Number of hips	Age (years)	Follow-up (years)	Approach	Survivorship with revision as the end point	Revision (hips, %)	Dislocation (hips, %)	Infection (hips, %)	Aseptic loosening (hips, %)
Mont et al. [19]	2006	52	38	3	AL	96.1% at 4 years	2 (3.8%)	1 (1.9%)	1 (1.9%)	1 (1.9%)
Kim et al. [4]	2010	93	38.2	11.1	PL	99% at 11 years	1 (1.1%)	2 (2.2%)	1 (1.1%)	0 (0%)
Kim et al. [20]	2011	73	45.5	8.5	PL	100% at 8 years	0 (0%)	1 (1.3%)	–	0 (0%)
Min et al. [5]	2013	162	51.5	7.2	AL	100% at 10 years	0 (0%)	3 (1.9%)	0 (0%)	0 (0%)
Ancelin et al. [21]	2016	149	44.7	11.6	AL (33), PL (116)	92.5% at 10 years	19 (12.8%)	9 (6.0%)	6 (4.0%)	2 (1.3%)
Current study	–	111	48.0	6	PL	98.2% at 6 years	2 (1.8%)	3 (2.7%)	1 (0.9%)	1 (0.9%)

THA total hip arthroplasty, ONFH osteonecrosis of the femoral head, AL anterolateral, PL posterolateral



multicenter registry study of 4995 hip arthroplasties for 3973 patients with ONFH in Japan [22], postoperative dislocation occurred in 5.2% of THAs. The authors identified the risk factors of dislocation that were younger ( $\leq 40$  years) or older ( $\geq 62$  years) age, higher body weight, posterolateral approach, and smaller head diameter. They were concerned about the relatively high dislocation in THA for patients with ONFH, and cautioned the risk factors for dislocation which is considered when selecting patients for THA. The main novelty of our study is the impact of CT-based navigation on dislocation rates in patients undergoing THA for ONFH. Our finding showed that use of the CT-based navigation improved component accuracy and this translated to clinical benefits such as reduced dislocation rates.

This study had several limitations. First, this was a retrospective study, and the follow-up period differed for each group. Therefore, we need to compare the outcomes between both groups at the 6-year follow-up, which was the mean follow-up period in the navigation group. Second, the use of large femoral head diameter was higher in the navigation group. In the future, prospective studies that adjusted factors (e.g., period of surgery, implant, and surgeon) are desired. Taking into consideration the difference, however, we performed the IPTW Cox regression analysis using a propensity score in relationship to sex, age at surgery, BMI, and femoral head size to mitigate bias, and the other analyses to confirm robustness also supported the result. In addition, as a result of sub-analysis that investigated dislocation rates by the difference in femoral head diameter, 10 of 79 hips (12.7%) from  $\leq 32$  mm head and 1 of 19 hips (5.3%) from  $\geq 36$  mm head occurred dislocation in the non-navigation group, respectively; 2 of 40 hips (5.0%) from  $\leq 32$  mm head and 1 of 71 hips (1.4%) from  $\geq 36$  mm head occurred dislocation in the navigation group, respectively. No statistical difference was observed between the group of head diameter  $\leq 32$  mm and that of  $\geq 36$  mm in the non-navigation ( $p = 0.324$ ) and navigation groups ( $p = 0.294$ ).

## Conclusion

Current study demonstrated that use of the CT-based navigation system provided a more precise placement of components than conventional manual techniques, and thus help prevent dislocation in patients with ONFH in the propensity score analysis.

**Acknowledgements** This work was partially supported by the Health Labor Sciences Research Grant H29-NANCHI-IPPAN#053.

## Compliance with ethical standards

**Conflicts of interest** The authors declare no conflict of interest.

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