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ORIGINAL PAPER

Does high hip centre affect dislocation after total hip arthroplasty for developmental dysplasia of the hip?

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Abstract

Background To achieve sufficient socket coverage by the native bone, high placement of cementless acetabular cup is often required. We previously reported, using computer simulation, that higher hip centre improved the bone coverage but decreased the range of motion in total hip arthroplasty (THA) for patients with hip dysplasia. However, in a clinical setting, the correlation between the hip centre height and dislocation after primary THA is still unclear. We examined whether a high hip centre affects dislocation after THA.

Methods A total of 910 patients, with 1079 dysplastic hips, who underwent primary THA were retrospectively reviewed. The age at THA averaged 63.0 years and mean follow-up was 74.3 months. Vertical centre of rotation (V-COR) was defined as the distance from the head centre to the interteardrop line. Uni- and multivariate logistic regression models were applied to identify significant factors affecting dislocation.

Results Ten hips in nine patients (0.9%) had dislocation after THA. In univariate analysis, age at surgery and V-COR were significant risk factors for dislocation. Multivariate analysis identified advanced age at operation (odds ratio [OR] 1.8/5 years), Crowe classification (OR 15.6), V-COR (OR 3.1/5 mm), and femoral head size (OR 11.6) as independent risk factors for dislocation. Receiver operating characteristic curve analysis revealed the cutoff value of the V-COR for dislocation as 23.9 mm.

Conclusions A higher hip centre with the V-COR > 23.9 mm affected dislocation after THA for DDH. Our results would be useful for reconstruction of the hip centre, particularly with cementless acetabular cups.

Keywords High hip centre · Centre of rotation (COR) · Developmental dysplasia of the hip (DDH) · Dislocation · Total hip arthroplasty

Introduction

Dislocation following total hip arthroplasty (THA) is the most frequently complications, and numerous factors affect its instability, including the surgical approach, condition of the surrounding soft tissues, and underlying diagnosis. Among these factors, an accurate component position is reportedly important [1–4]. The safe zone for cup placement (inclination, 40 ± 10°; anteversion, 15 ± 10°) proposed by Lewinnek et al. [5], when employed, decreases the incidence of dislocation after primary THA. Moreover, the anatomical positioning of the acetabular cup can reduce the failure rate of THA [6].

Developmental dysplasia of the hip (DDH) is a common underlying condition leading to secondary osteoarthritis (OA) of the hip [7]. Due to the acetabular morphology in DDH, including bone deficiency in the acetabular roof, it is frequently difficult to reconstruct the

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acetabular cup at the anatomical centre in severe DDH to achieve sufficient bone coverage [8]. Morselized or structural bone grafting is one option for cup placement at the anatomical hip centre. However, bone grafting may reduce the bone-implant contact that is essential for biological fixation particularly with cementless acetabular cups. To avoid the insufficient socket coverage by the native bone, high placement of a cementless acetabular cup is often required [9, 10].

From a biomechanical perspective, a high hip centre is still a controversial topic. One study accepted a high hip centre without superolateral cup placement, including heights of up to 37 mm from the normal anatomical hip centre [11]. By contrast, another study revealed that cup reconstruction at the anatomical centre was recommended because such relocation decreased the hip joint reaction force [12]. We previously reported that a higher hip centre improved the bone coverage but decreased the range of flexion and internal rotation in THA, using computed tomography-based computer simulation software [10]. In the clinical setting, it is unclear whether a high hip centre is a risk factor for dislocation after THA. To the best of our knowledge, the correlation between the hip centre height and dislocation after primary THA has not been examined. Therefore, we investigated whether a high hip centre affects dislocation after THA for DDH.

Materials and methods

Patients

Before initiation of the present study, institutional review board approval was obtained. Between January 1998 and March 2015, a total of 1124 hips in 947 patients performed primary cementless THA for secondary OA because of DDH at our institution. All pre-operative anteroposterior pelvic radiographs were reviewed to group the patients based on Crowe classification of DDH severity assigned. Crowe types I to IV were 799 hips, 238 hips, 66 hips, and 21 hips, respectively [13]. Thirty-seven patients were unable to follow up for more than 12 months post-operatively, and these patients were also excluded. These exclusions left us with 1079 hips in 910 patients. The detail of patients is listed in Table 1. There were 820 women and 90 men with a mean age at surgery of 63.0 ± 9.9 years (range, 30–93 years) and a mean body mass index of 23.8 ± 3.6 kg/m^2 (range, 15.0–45.2 kg/m^2). Mean post-operative follow-up was 74.3 ± 49.5 months (range, 12–218 months). All patients were followed up prospectively, with follow-up visits scheduled at two months, six months, and one year after THA, and annually thereafter.

Table 1 Demographic data

Number of patients (hips)	910 (1079)
Age at THA (years old)*	63.0 ± 9.9 (30–93)
Female/male, *n* (%)	820 (90.1%)/90 (9.9%)
Crowe types I/II, III, and IV, *n* (%)	656 (72.1%)/190 (27.9%)
Height (cm)*	152.2 ± 7.3 (132–178)
Body weight (kg)*	55.3 ± 10.0 (32.9–105.0)
BMI (kg/m^2)*	23.8 ± 3.6 (15.0–45.2)
Follow-up period (months)*	74.3 ± 49.5 (12–218)

BMI body mass index

*Mean ± standard deviation (range)

Surgical technique

Each operation was performed using the modified posterolateral approach, and the posterior soft tissue was repaired using the method of Pellicci et al. [14, 15]. Six experienced hip surgeons performed the operation, each having an experience of > 50 THAs/year. The combined anteversion technique was adopted at our institution in 2006 by one of us (YN), and after 2011, all surgeons performed THA using this technique [16]. Cup anteversion was defined as operative anteversion. In the combined anteversion technique, the femur was prepared first in order to determine its anteversion before the cup placement. We measured the anteversion of the final broach as the angle between the lower leg axis and the trial stem axis by flexing the knee and placing the tibia in a vertical position using a manual goniometer. Subsequently, the cup anteversion was adjusted according to the stem anteversion to achieve combined anteversion ranged from 40 to 60° [16]. In cases requiring high placement of acetabular cup, the acetabulum was reamed adjacent to the medial wall of the pelvis to maximize the bone coverage targeting the cup centre-edge angle more than 0° [17] (Fig. 1). To avoid extremely high cup placement, the acetabulum was reamed not in superomedial direction but in medial direction without violating anterior and posterior wall. Two or three screws were used to enhance the initial fixation of the acetabular cup.

Implants

We used mainly two cementless stems, PerFix or PerFix-910 (Kyocera, Kyoto, Japan). PerFix was used in 188 hips by the year 2004, while PerFix-910 was used in 658 hips [18]. The Versys cementless stem (Zimmer, Warsaw, IN) was used in 45 hips, and the S-ROM stem (Depuy, Warsaw, IN) was used in 19 hips. We used cementless acetabular cups in all primary THAs, which were included the AMS HA cup (Kyocera) in 854 hips and the TM cup (Zimmer) in 56 hips [19]. Head size was changed depending on the period and cup size: 22 mm in

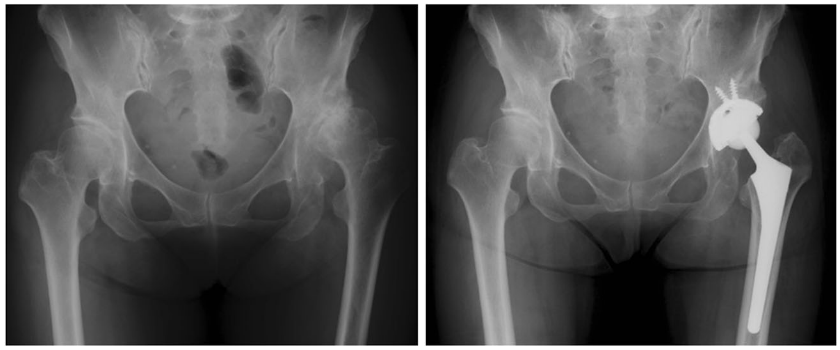

Fig. 1 Anteroposterior radiographs of before and after total hip arthroplasty. Acetabular cup placement

153 hips, 26 mm in 382 hips, 28 mm in six hips, and 32 mm in 369 hips. Fifty-seven hips were reconstructed with a flat-rim liner, while 853 hips used an elevated liner.

Radiologic assessments

Cup inclination was defined as the abduction angle, using the interteardrop line as the baseline (Fig. 2). Cup anteversion was calculated from anteroposterior radiographs using the method of Lewinnek et al. [5] (Fig. 3). The length of the long axis of the ellipse was defined as "L," the length of the short axis of the ellipse was defined as "S," and cup anteversion was calculated as arcsine (S/L), as we previously reported [18]. We measured vertical centre of rotation (V-COR), which was defined as the vertical distance along a line extending from the center of the femoral head perpendicular to the interteardrop line [9, 10] (Fig. 2). We also measured horizontal centre of rotation (H-COR), which was defined as the horizontal distance along the interteardrop line extending laterally from the inferior point of the teardrop to a perpendicular line dropped from the centre of the femoral head [10] (Fig. 2).

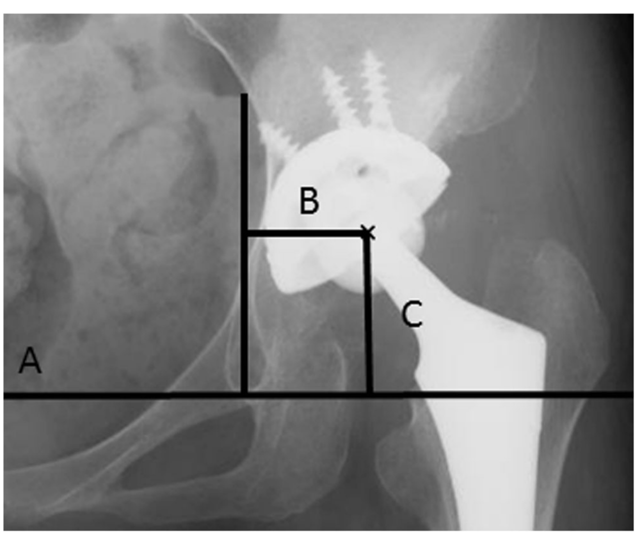

Fig. 2 The definition of parameters. (A) Interteardrop line. (B) Horizontal centre of rotation (H-COR). (C) Vertical centre of rotation (V-COR)

Statistical analysis

To identify the significant factors for dislocation after THA, we performed univariate logistic regression analysis. Then, a multivariate logistic regression model was developed to identify the important factors. In order to satisfy the statistical assumption of an independent observation, we selected only one hip randomly from each patient who performed bilateral THA as there were no significant differences in the laterality of the V-COR and post-operative follow-up period. Receiver operating characteristic (ROC) curves were created to calculate the cutoff value of the V-COR for dislocation. Statistical analyses were performed using JMP version 12.0 (SAS Institute, Cary, NC), with statistical significance defined as $p < .05$.

Results

Dislocation occurred in ten hips in nine patients (0.92%) (Fig. 4). These included seven women and two men with a

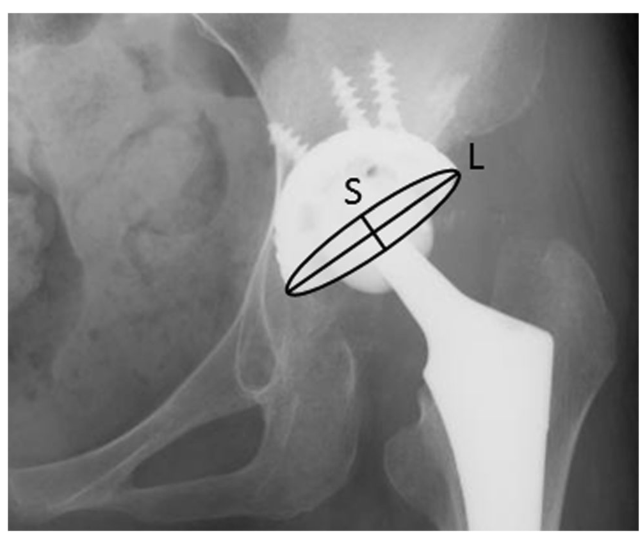

Fig. 3 The definition of parameters. (S) Length of the short axis of the ellipse. (L) Length of the long axis of the ellipse. Cup anteversion is calculated as arcsine (S/L)

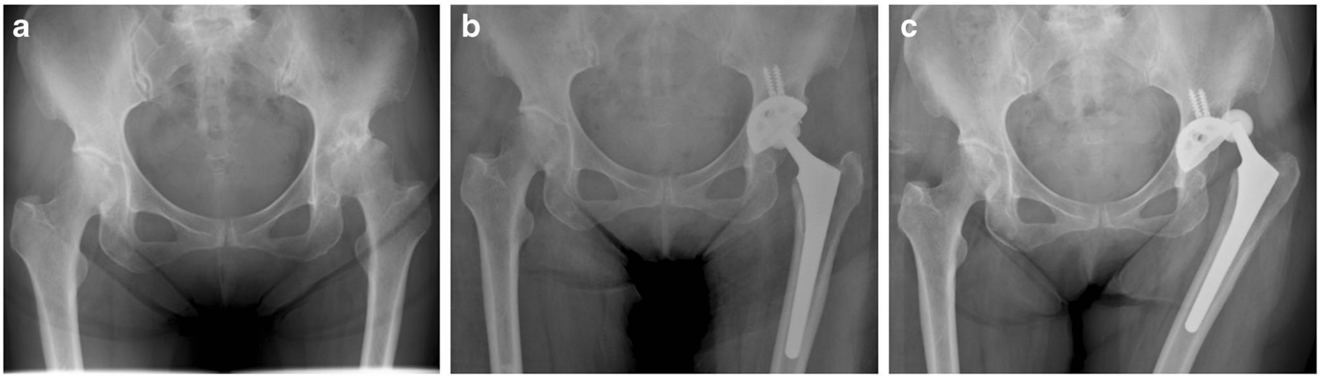

Fig. 4 Anteroposterior radiographs of a 68-year-old woman, a case of dislocation (**a**) left side osteoarthritis with developmental dysplasia of the hip (**b**) at 2 weeks post-operatively; vertical centre of rotation was 26.2 mm (**c**) at 6 months post-operatively; posterior dislocation occurred when she picked up something on the floor

mean age at surgery of 69.6 ± 7.6 years (range, 58–83 years). The V-COR and H-COR of dislocation cases averaged 29.7 ± 6.5 mm (range, 23.8–41.7 mm) and 36.4 ± 4.5 mm (range, 29.6–42.7 mm), respectively. Sharp's angle in the dislocated cases averaged 47.4 ± 6.1° (range, 40.4–58.9°), pre-operatively [20]. The anterior and posterior dislocations were noted in two and seven hips, respectively. The stem anteversion of the dislocation cases averaged 22.7 ± 10.9° (range, 7.2–40.7°). The S-ROM stem was used in one case of dislocation with big femoral anteversion to correct the component position. Among the ten hips, only one hip required revision THA due to recurrent dislocations. In univariate analysis, the age at surgery (62.9 ± 9.9 years vs 69.6 ± 7.6 years, $p = 0.0411$) and V-COR (24.1 ± 6.7 mm vs 29.7 ± 6.5 mm, $p = 0.0206$) were significant risk factors for dislocation (Table 2). No significant differences were found in gender, height, body weight, BMI, Crowe classification, cup abduction, cup anteversion, H-COR, stem type, cup type, or femoral

Table 2 Results of univariate logistic regression of associate factors for the dislocation after total hip arthroplasty (THA)

Parameters	Stable cases ($n = 901$)	Dislocated cases ($n = 9$)	Crude odds ratio (95% CI)	p values
Age at THA (years old)	62.9 ± 9.9	69.6 ± 7.6	1.07 (1.00–1.15)	0.0411*
Gender			0.38 (0.09–2.57)	0.2747
Male, *n* (%)	88 (97.8%)	2 (2.2%)		
Female, *n* (%)	813 (99.1%)	7 (0.9%)		
Height (cm)	152.2 ± 7.3	154.8 ± 6.2	1.05 (0.96–1.14)	0.2867
Body weight (kg)	55.2 ± 10.0	54.2 ± 10.6	0.99 (0.92–1.05)	0.75
BMI (kg/m^2)	23.8 ± 3.6	22.5 ± 3.6	0.89 (0.73–1.10)	0.2646
Crowe classification			1.56 (0.28–6.59)	0.6955
Crowe I, *n* (%)	649 (98.9%)	7 (1.1%)		
Crowe II, III, and IV, *n* (%)	252 (99.2%)	2 (0.8%)		
Cup abduction (°)	39.5 ± 6.0	43.1 ± 8.1	1.11 (0.99–1.23)	0.0707
Cup anteversion (°)	10.4 ± 6.6	12.7 ± 7.0	1.05 (0.96–1.15)	0.3292
V-COR (mm)	24.1 ± 6.7	29.7 ± 6.5	1.11 (1.02–1.20)	0.0206*
H-COR (mm)	34.4 ± 5.2	36.4 ± 4.5	1.08 (0.95–1.21)	0.2443
Head size			2.47 (0.59–16.65)	0.2267
< 28 mm, *n* (%)	528 (98.7%)	7 (1.3%)		
≥ 28 mm, *n* (%)	373 (99.5%)	2 (0.5%)		
Stem design			6.13 (0.32–36.08)	0.1758
Press fit type, *n* (%)	883 (99.1%)	8 (0.9%)		
Modular type, *n* (%)	18 (94.7%)	1 (5.3%)		
Cup design			1.92 (0.24–15.6)	0.4369
AMS HA cup, *n* (%)	846 (99.1%)	8 (0.9%)		
TM cup, *n* (%)	55 (98.2%)	1 (1.8%)		
Liner			0.53 (0.07–4.31)	0.5836
Elevated liner, *n* (%)	845 (99.1%)	8 (0.9%)		
Flat liner, *n* (%)	56 (98.3%)	1 (1.7%)		

Continuous values are expressed as mean ± SD

95% CI 95% confidence intervals, *BMI* body mass index, *V-COR* vertical hip center of rotation, *H-COR* horizontal hip center of rotation

*Statically significant p value < 0.05

Table 3 Results of multivariate logistic regression of associate factors for the dislocation after total hip arthroplasty (THA)

Parameters	Adjusted odds ratio	95% confidence interval	*p* values
Age at THA (per 5-year increase)	1.82	1.20–2.96	0.0047*
Gender	0.42	0.08-3.50	0.3811
BMI	5.02	0.69–127.88	0.1228
Crowe classifications I/II, III, and IV	15.6	1.76–155.96	0.0119*
Cup abduction	1.06	0.93–1.20	0.3820
Cup anteversion	1.11	0.98–1.24	0.0853
V-COR (per 5 mm increase)	3.11	1.60–6.80	0.0006*
H-COR	1.06	0.93–1.22	0.3840
Head size < 28 mm/≥ 28 mm	11.6	1.43–255.97	0.0191*
Stem type press fit/modular	9.63	0.27–208.05	0.1855
Cup type AMS HA cup/TM cup	10.2	0.21–449.54	0.2178
Liner type elevated/flat	0.10	0.04–3.46	0.1751

BMI body mass index, *V-COR* vertical hip center of rotation, *H-COR* horizontal hip center of rotation

*Statically significant *p* value < 0.05

head size. Multivariate analysis demonstrated that the age at surgery, Crowe classification, V-COR, and femoral head size were independent risk factors for dislocation (Table 3). Each increase of five years in the age resulted in a 1.8-fold rise in the risk of dislocation (95% confidence interval [CI], 1.20–2.96; $p = 0.0047$). Patients with Crowe types II, III, and IV had a 15.6-fold higher risk of dislocation than those with Crowe type I (95% CI, 1.76–155.96; $p = 0.0119$). Each increase of 5 mm in the V-COR resulted in a 3.1-fold rise in the risk of dislocation (95% CI, 1.60–6.80; $p = 0.0006$). Patients with a femoral head size < 28 mm had a 11.6-fold higher risk of dislocation than those with a femoral head size ≥ 28 mm (95% CI, 1.43–255.97; $p = 0.0191$).

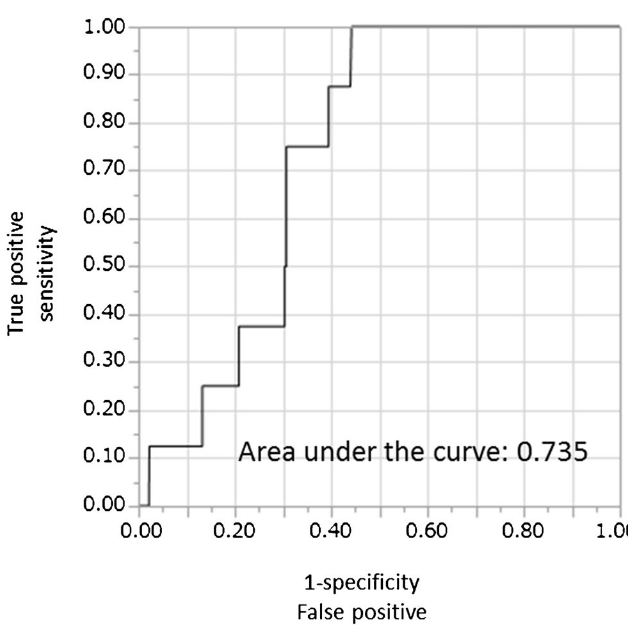

Fig. 5 Receiver-operator coefficient (ROC) curve for dislocation

Based on the ROC curve analysis, the cutoff value of the V-COR for dislocation was 23.9 mm (Fig. 5). The area under the ROC curve was 0.735, sensitivity was 1.00, and specificity was 0.60.

Discussion

In this study of 1079 hips in 910 patients with DDH, dislocation occurred in ten hips in nine patients (0.92%). Multivariate analysis identified advanced age, Crowe classification, V-COR, and femoral head size as independent risk factors for dislocation after THA for DDH. According to the ROC curve analysis, the acceptable V-COR in patients with DDH was 23.9 mm in terms of the post-operative dislocation. Our results would be useful for the reconstruction of hip centre, particularly with cementless acetabular cups.

Reportedly, DDH is a risk factor for the post-operative dislocation with a wide range of dislocation rate [3]. Wang et al. reported dislocation in 24 (2.93%) of 820 hips in patients with DDH [21]. Ito et al. showed an 8.8% dislocation rate in a series of 113 DDH hips in patients with DDH [22]. The current study showed a dislocation rate of 0.92%, which is lower than that reported in the previous studies. One cause for this low dislocation rate was thought to be the use of larger femoral heads. A larger head size decreased the dislocation rate: 1.3% (7/535) with < 28 mm and 0.5% (2/375) with ≥ 28 mm. Multivariate analysis in our study identified that patients with < 28 mm had an 11.6-fold higher risk of dislocation than those with ≥ 28 mm (95% CI, 1.43–255.97; $p = 0.0191$). In addition, the combined anteversion might have reduced the dislocation rate [16]. It is well known that femoral anteversion in DDH varies. Akiyama et al. reported that the femoral anteversion in DDH ranged from − 13.2° to 58.2° with a significantly wider distribution of values than that in normal hips [23]. Adjusting the cup anteversion to stem anteversion by combined anteversion technique might prevent dislocation [16]. Moreover, it was reported that double mobility cups decrease the risk of post-operative dislocation in high-risk patients in primary THA [24]. Based on this study, the patients with the V-COR > 23.9 mm, the femoral head size < 28 mm, advanced age, and Crowe II, III, and IV had high risks for dislocation. It might be one of the options to use a double mobility cup for these patients.

Previous reports have shown excellent outcomes of cementless THA for DDH with a higher hip centre. Kaneuji et al. showed that the mean V-COR was 26.8 ± 4.8 mm (range, 20–35.9 mm), and there were no acetabular failures at a mean of 15 years [25]. Murayama et al. demonstrated that clinical and radiographic outcomes were excellent with placements of < 35 mm from the interteardrop line [26]. For revision THA, Morag et al. revealed a significant correlation between cup height and functional outcome, with better outcome and survivorship with a cup placement of < 35 mm proximal to the interteardrop line [27]. In terms of the implant longevity and clinical score, V-COR of approximately 35 mm might be acceptable. From a biomechanical perspective, Doehring et al. showed that no superolateral relocation was noted regarding hip joint force until 37 mm from the normal anatomical level [11]. In terms of the range of motion, our previous study using computer simulation demonstrated that an acceptable V-COR in patients with DDH was 35 mm [10]. The significant effect of hip centre on post-operative dislocation after primary THA has not been previously reported in a clinical setting. The current study revealed that each increase of 5 mm in the V-COR resulted in a 3.1-fold rise in the risk of dislocation and that an acceptable V-COR was 23.9 mm in terms of dislocation after THA.

Multivariate analysis identified not only the V-COR but also advanced age, Crowe classification, and femoral head size as independent risk factors for dislocation after THA. It has been reported previously that patient age is associated with dislocation after primary THA [2]. Serious changes due to aging include change in pelvic inclination and progressive decline in bone quality and muscle volume [28]. These phenomena related to aging could increase the risk of dislocation after THA. Regarding Crowe classification, our results agree with those of another study [28]. Cameron et al. revealed that a high Crowe grade is correlated to a high chance of complications, such as nerve palsy, infection, and dislocation. Crowe classification can predict the complexity of surgery, with an increase in the Crowe grade making complications more common [29]. Utility of larger head size has been demonstrated to prevent dislocation after THA [4, 16]. In previous studies, it tended to provide better stability among patients with DDH, particularly when increased from 28 to 32 mm [21]. Our results revealed that, although a relatively small pelvis of a patient with DDH might limit the selection of larger femoral head sizes, 28 and 32 mm could compensate for a possible instability.

This study has several limitations. First, this study was not prospective and randomized. Therefore, the precise effect of the hip center height on post-operative dislocation should be further confirmed in a randomized controlled study. Second, the number of patients with dislocation after THA was small, and a small sample size might have decreased the statistical reliability of our study. A larger number of subjects in a multicenter study could provide more accurate and statistically reliable results. However, with a larger sample size, several factors including the number of surgeons and types of implant and approach would vary widely, which could make the analysis less precise. Third, the effects of stem version and combined anteversion on dislocation were not evaluated in our study as we were unable to measure the stem version precisely using plain radiography. We previously reported that the stem version evaluated using cross-table radiography differed from the true stem version measured using computed tomography [30]. Further prospective studies should be performed to clarify stem version using post-operative computed tomography, if available. Fourth, because a posterolateral approach was used in all cases, our findings might differ from those of the studies using a different approach. As the posterolateral approach is the only approach performed at our institution, it would be difficult to compare its findings with those of the other approaches. Fifth, DelSole et al. showed that lumbar inclination and sagittal spinal deformity (SSD) influenced the hip prosthesis stability and concluded that patients with SSD have a THA dislocation rate of 8% and a revision for instability rate of 5.8% [31]. Although the effects of lumber inclination and SSD were not examined in our study, we would like to consider them in the future. Next, we did examine the effect of high hip centre on the dislocation but not on the patients' outcome. Further study is needed to clarify the effects of hip centre on the pain, the activity of daily life, and the range of motion in a clinical setting. Finally, we could not measure the V-COR pre-operatively, because the femoral heads in many cases were too deformed to measure the V-COR. However, it would be interesting to show the actual change of the hip centre in before and after THA for DDH.

Conclusion

A higher hip centre with the V-COR > 23.9 mm was found to be a risk factor for dislocation after THA for DDH. Furthermore, advanced age, Crowe classification, and femoral head size were independent risk factors for dislocation. Our results would be useful for reconstruction of the hip centre, particularly with cementless acetabular cups.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The institutional review board approved this study (IRB number 27-408).

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