Does Degree of the Pelvic Deformity Affect the Accuracy of Computed Tomography-Based Hip Navigation?

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**DOES DEGREE OF THE PELVIC DEFORMITY AFFECT
THE ACCURACY OF COMPUTED TOMOGRAPHY-BASED
HIP NAVIGATION?**

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Abstract:

Some navigation systems have been used for improvement of component positioning, there have been few reports regarding cases of severe pelvic deformity. We performed a retrospective review of 25 cases of THA with a computed tomography (CT)-based navigation system in patients with severe pelvic deformities and estimated acetabular component position and angle between severe deformity group and mild dysplastic group as a control. There were no significant differences in accuracy of navigation system between two groups in terms of three-dimensional component position or angle. Accuracy of CT-based hip navigation does not depend on the degree of pelvic deformity, and this system is also useful to identify acetabular orientation and for precise component implantation in cases of pelvic deformity.

Keywords:

total hip arthroplasty, pelvic deformity, computed tomography (CT)-based navigation system, acetabular component, developmental dysplasia.

Brief title:

Hip Navigation in Severe Pelvic Deformity

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5 **Abstract**

6 Some navigation systems have been used for improvement of component positioning, there have been
7 few reports regarding cases of severe pelvic deformity. We performed a retrospective review of 25 cases
8 of THA with a computed tomography (CT)–based navigation system in patients with severe pelvic
9 deformities and estimated acetabular component position and angle between severe deformity group and
10 mild dysplastic group as a control. There were no significant differences in accuracy of navigation system
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12 hip navigation does not depend on the degree of pelvic deformity, and this system is also useful to
13 identify acetabular orientation and for precise component implantation in cases of pelvic deformity.

14
15 **Introduction**

16 The position of the acetabular component affects the results of total hip arthroplasty (THA) in terms of
17 postoperative range of motion, dislocation, impingement, wear and osteolysis, and is also associated with
18 long–term implant survival [1–4]. Precise positioning of the acetabular components in the normal native
19 acetabulum also decreases shearing force on the component, and is thought to be ideal from a

20 biomechanical viewpoint [4, 5]. Modification of the operative procedures and breakthroughs in implant
21 technology have made it possible to perform THA even in patients with severe deformities. However, it is
22 very difficult to place the acetabular component in the appropriate position in cases with severe acetabular
23 deformity either freehand or with a mechanical device because of the difficulty of identifying the
24 orientation around the acetabulum [3, 6, 7]. Although various navigation systems, including imageless,
25 fluoroscopy-based and computed tomography (CT)-based navigation systems, have been developed to
26 improve component positioning in THA and their usefulness has been reported [2, 6–10], there have been
27 few reports regarding the accuracy of these navigation systems in THA in cases with severe acetabular
28 deformities. For the treatment of such cases, we have used an intraoperative CT-based navigation system
29 for more precise implantation of acetabular components. The goal of the present study was to implant
30 acetabular component accurately in normal native acetabulum using CT-based navigation system in the
31 cases of severe pelvic deformity and to compare the accuracy of this system with regard to
32 three-dimensional component position and angle with that of mild dysplastic group as a control

33

34 **Materials and Methods**

35 From May 2006 to April 2011, we performed a retrospective review of 25 hips in 22 patients with severe
36 pelvic deformities and matched 25 hips in 25 patients with low-grade subluxation as a control group. The
37 degree of subluxation in the dysplastic hip was graded according to the classification of Crowe *et al* [11].
38 Three patients in the study group had bilateral THAs. The patients' demographics are shown in Table 1.

39 With the exception of the diagnosis, there were no significant differences in age, sex, side, height, weight
40 or body mass index between the two groups. Preoperative diagnoses in the study group included severe
41 developmental dysplasia of Crowe group III (75% – 100% subluxation) in 9 hips and Crowe group IV (>
42 100% subluxation) in 9 hips, ankylosis in 3 hips, destructive arthritis after infection in 1 hips, Charcot
43 joint in 1 hip and one arthrodesed hip. Preoperative diagnoses in the control group were Crowe group I in
44 18 hips and primary osteoarthritis in 7 hips. Although femoral valgus osteotomy was performed in two
45 cases and arthrodesis was performed in one case in the study group before THA, no previous operation in
46 the pelvic side was performed between both groups.

47 Preoperative CT scan from the iliac wing to the femoral condyle was performed using a helical CT
48 scanner (LightSpeed VCT, GE Medical Systems, Milwaukee, WI). The slice thickness was 1mm, and the
49 pitch was 2.5–3.0 mm (almost 160–250 slices dependant on body constitution). The CT data were
50 transferred to the planning module. Then, preoperative planning was performed to determine the optimal
51 component size, angle and position using three-dimensional templating software (CT-based Hip, Version
52 1.0; Stryker Navigation, Freiburg, Germany). The acetabular component position was determined to place
53 the implant at the site of the normal acetabulum, and the target angle of the components was set at
54 anatomical inclination of 40° and anteversion of 20° which were equal to 38.3° of inclination and 12.7° of
55 anteversion in radiographic manner [12]. The anterior pelvic plane (APP) defined by both the bilateral
56 anterior superior iliac spine (ASIS) and pubic tubercle was used as a reference plane of the pelvis. If this
57 plane was tilted in sagittal plane when the patient was lying in the supine position due to spine and pelvic

deformities, the correction of anterior–posterior axis was performed in both groups during preoperative templating according to the previous studies [10], in brief, “functional pelvic plane“ was used as a reference plane [13].

All surgeries were performed by a single surgeon (senior author, TK) through a posterolateral approach in the lateral decubitus position under general anaesthesia using a CT–based and surface registration–type hip navigation system (CT–based Hip, Version 1.0; Stryker Navigation). Intraoperative surface registration was performed according to the method reported previously by Sugano *et al* [10]. Briefly, a reference tracker was mounted on the pelvic wing and surface matching was performed by touching more than 30 points around the acetabulum with a pointer after resection of the femoral head. In severe deformity group, digitising area were determined as wide as possible including native acetabulum, pseudo acetabulum, the ala of the ilium, acetabular rim and posterior wall. The additional time for setup and registration of navigation system was almost five to ten minutes in both groups. After registration, it was possible for the surgeon to ream the acetabulum and implant the acetabular component with real–time confirmation of both the component position and angle on the navigation monitor. In this study, femoral components were implanted without use of the navigation system. In seven hips in the study group, subtrochanteric osteotomies were performed to prevent neurological problems, such as sciatic nerve palsy, due to the large degree of limb lengthening necessary (> 4 cm) and in the cases of excessive femoral anteversion, derotation was performed at subtrochanteric osteotomy site or using modular stem. The acetabular components used in both groups consisted of the same press fit titanium shell (TriAD®;

77 Stryker Orthopaedics, Mahwah, NJ). The superolateral acetabular defect was filled with morselized
78 autograft obtained from the reamed bone and femoral head. After implantation of the acetabular
79 component, final cup orientation was recorded (intraoperative record).

80 The postoperative CT scan was performed at about 10 days after the operation in all cases and was
81 uploaded to the same planning module to determine the postoperative component position and angle. We
82 made the same coordinate plane manually as the plane determined in preoperative planning on the
83 workstation, and measured various parameters to allow superposition of virtual computer-aided design
84 (CAD) models of the acetabular component on the images of the actual implanted component (Fig. 1) [14,
85 15]. We evaluated the deviation of the three-dimensional position of the acetabular component from the
86 center of the anterior pelvic plane between the position planned preoperatively and that calculated from
87 postoperative CT scans. In addition, the deviation of anatomical anteversion and inclination angle
88 between the preoperative plan, the intraoperative records from the navigation system and the data from
89 postoperative CT scans were evaluated. We also investigated whether the size of the component planned
90 preoperatively was the same as that actually implanted. Intraoperative error was evaluated by root mean
91 square (RMS) analysis of registration to compare the accuracy of the registration process between the two
92 groups [16]. Measurements were performed by the author (YK) who was independent of the operating
93 surgeon. To reduce intra-observer error, each measurement was performed three times and the mean
94 value was used. The inter-observer variability of postoperative measurements was also assessed in the
95 first 10 hips by two other authors (SI, KK). Informed consent was obtained from the patients and the

96 research protocol was approved by the hospital investigational review board. The authors received no
97 benefits or funds in relation to this study.

98

99 **Statistical analysis**

100 A mean difference of 3° and 3 mm in navigation accuracy of the cup placement was identified as
101 significant according to a previous report [8]. Then a sample size power analysis was performed and
102 showed that 24 patients in each group would be sufficient to determine whether there was a significant
103 difference with the power = 0.8 and $P < 0.05$. All statistical analyses were performed using SPSS ver.
104 19.0 (SPSS Inc., Chicago, IL). Mann–Whitney U test was used to compare the categorical data and the χ^2
105 test or Fisher’s test was applied to compare the nominal observations. In all analyses, $P < 0.05$ was taken
106 to indicate statistical significance.

107

108 **Results**

109 The mean deviations between preoperative planning and the actual component position were 3.2 ± 2.5
110 mm for the horizontal position, 3.4 ± 3.6 mm for the vertical position and 3.3 ± 2.3 mm for the
111 anteroposterior position in the study group and 2.7 ± 2.3 mm, 2.7 ± 1.7 mm and 2.7 ± 1.7 mm,
112 respectively, in the control group. There were no significant differences ($P=0.719$, 0.696 , and 0.609 ,
113 respectively) between the two groups (Table 2).

114 Intraoperative records were $39.4^\circ \pm 1.4^\circ$ inclination and $19.3^\circ \pm 2.0^\circ$ anteversion, respectively, in the

115 study group and $39.0^{\circ} \pm 1.6^{\circ}$ and $19.4^{\circ} \pm 1.7^{\circ}$, respectively, in the control group. Postoperative
116 measurements were $39.5^{\circ} \pm 1.7^{\circ}$ and $17.5^{\circ} \pm 2.9^{\circ}$, respectively, in the study group and $38.1^{\circ} \pm 1.8^{\circ}$ and
117 $17.7^{\circ} \pm 2.9^{\circ}$, respectively, in the control group.

118 The mean deviations between preoperative planning and postoperative measurement were $1.5^{\circ} \pm 1.2^{\circ}$
119 inclination and $2.9^{\circ} \pm 1.8^{\circ}$ anteversion in the study group and $2.0^{\circ} \pm 1.7^{\circ}$ and $3.2 \pm 1.8^{\circ}$, respectively, in
120 the control group (Table 3, Fig. 2). The mean deviations between intraoperative records and postoperative
121 measurement were $1.5^{\circ} \pm 1.2^{\circ}$ and $2.5^{\circ} \pm 1.7^{\circ}$, respectively, in the study group and $1.4^{\circ} \pm 1.1^{\circ}$ and $2.7^{\circ} \pm$
122 1.4° , respectively, in the control group (Table 3). There were no significant differences between the two
123 groups ($P=0.657$, 0.632 , 0.744 and 0.645 , respectively). There were no complications related to use of the
124 navigation system. The intraclass correlation coefficients (ICC) of the intra-observer measurement in
125 inclination and anteversion were 0.826 and 0.823 , respectively. ICC of the measurements in the horizontal
126 position, vertical position, and anteroposterior position were 0.995 , 0.999 and 0.999 , respectively. ICC of
127 the inter-observer measurement were 0.824 and 0.865 , respectively and that of the measurements in the
128 horizontal position, vertical position, and anteroposterior position were 0.987 , 0.993 and 0.997 ,
129 respectively. The accuracy of planning of the component size and RMS error of registration are shown in
130 Table 4. There were no significant differences in the accuracy of planning of the component size and
131 RMS error between the two groups ($P=0.702$ and 0.612).

132 Representative cases are shown in Figs. 3 and 4.

133

134 **Discussion**

135 Malpositioning of the acetabular component in THA increases the risk of reduced postoperative range of
136 motion, dislocation, impingement, wear, osteolysis, *etc* [1–4]. Acetabular component malpositioning was
137 reported as the single greatest factor determining the likelihood of both early and late revision surgery
138 [17]. Lewinnek [18] investigated cases of postoperative dislocation and proposed a so-called “safe zone”
139 of the acetabular component with radiographic inclination of $40^{\circ} \pm 10^{\circ}$ and anteversion of $15^{\circ} \pm 10^{\circ}$.
140 Using a mathematical model, Widmer *et al.* [19] suggested combined femoral and acetabular anteversion
141 to avoid impingement and achieve better postoperative range of motion. In our hospital, the target is to
142 implant the acetabular component at the normal native acetabulum if possible, with anatomical inclination
143 of 40° and anteversion of 20° which were equal to 38.3° of inclination and 12.7° of anteversion in
144 radiographic manner [12] and which were almost center of the safe zone defined by Lewinnek. From the
145 biomechanical viewpoint, it is thought to be ideal to implant the acetabular component in the normal
146 acetabulum [20]. Stans *et al.* [5] reviewed 82 patients with Crowe type III dysplasia undergoing cemented
147 total hip arthroplasty, and reported that loosening of the acetabular components occurred significantly
148 more frequently for those positioned outside compared to those inside the true acetabular region.

149 However, it is extremely difficult even for expert surgeons to place the acetabular component in the
150 appropriate position in a freehand manner or using a conventional mechanical device in cases of severe
151 acetabular deformity caused by severe developmental dysplasia, arthrodesed hip, *etc.* [4, 6, 7, 21] This is
152 because the acetabulum in such cases has many deformities and bone defects, and there is neither a

153 normal acetabular rim nor soft tissues, such as transverse acetabular ligament, to enable the surgeon to
154 implant the component accurately [3,4]. These deformities are also related to the risk of postoperative
155 complications [20].

156 On the other hand, many types of navigation system, including imageless, fluoroscopy-based and
157 CT-based navigation systems, have been developed and have been shown to improve the accuracy of
158 component positioning in THA and reduce postoperative complications [2, 6–10]. Imageless and
159 fluoroscopy-based navigation systems have some advantages with regard to both radiation exposure and
160 the lack of a necessity for intraoperative surface matching [2, 9]. However, these navigation systems were
161 based on the morphology of the normal pelvis and therefore there is a risk of marked registration
162 deviation and misalignment of the component in cases with severe acetabular deformities [8]. With the
163 exception of a few case reports, there have been no previous investigations regarding the accuracy of
164 these navigation systems in THA for the cases with severe acetabular deformities [6, 7].

165 In such cases, we used both preoperative three-dimensional templating and an intraoperative surface
166 registration type CT-based navigation system to estimate whether the target position and angle of the
167 component can be achieved, to facilitate precise implantation. Kalteis reported that this type of navigation
168 system has advantages over imageless navigation systems in patients with abnormal anatomy, such as hip
169 dysplasia, posttraumatic deformities or in revision procedures [8]. The CT-based navigation system used
170 in the present study requires a preoperative CT scan, preoperative templating and intraoperative surface
171 registration [10], and therefore it has disadvantages in terms of both cost and radiation exposure [16].

172 However, accurate component implantation is especially important in cases of severe deformity. Sugano
173 *et al.* [22] investigated the mid-term results of cementless ceramic-on-ceramic THA with and without a
174 CT-based navigation system similar to that used in the present study. They concluded that the navigation
175 system made it possible to achieve acetabular orientation within the safe zone with reduced variance, and
176 that there were higher rates of postoperative dislocation and mechanical problems related to impingement
177 in the non-navigated group than in the navigated group because of malorientation of the acetabular
178 component. In the present study, the accuracy of component placement was significantly improved by
179 using the CT-based navigation system in patients with severe acetabular deformity. In addition, there
180 were no significant differences between the severe deformity group and the control group in terms of the
181 mean component position or angle. Pelvic deformities in the study group could affect the accuracy of the
182 intraoperative registration, however there was no significant reference in RMS analysis of surface
183 registration in both groups.

184 The present study had some limitations. First, the number of patients included in the study was small
185 since severe pelvic deformities such as Crowe III and IV were extremely rare and there might be some
186 type II errors. Second, this was not a randomised and retrospective study. The selection of patients of the
187 severe pelvic deformity was our own criteria and the pathologies in the study group were heterogeneous.
188 Additionally, pathologies in both groups were not the same. However there were no significant
189 differences in age, sex, side, height, weight or body mass index between the two groups and the patients'
190 demographic factors were unlikely to affect the results. Third, clinical results were lacked in the present

191 study since postoperative follow-up period was short. There was only one case of posterior dislocation in
192 the cases of Crowe IV dislocated hip in the study group in early postoperative period due to inappropriate
193 femoral anteversion and soft tissue imbalance, not a malposition of the acetabular component. And it was
194 single event and didn't repeat any more. Also, there were no other major complications associated with
195 cup position such as leg length discrepancy, iliopsoas pain, and so on. To elucidate the effectiveness of
196 this type of navigation system, it will be necessary to accumulate long-term clinical results, including
197 data regarding dislocation rate, implant survival and wear rate with or without this type of navigation
198 system. However, our results were consistent with those of previous studies, and suggest that this system
199 is useful for cases with severe acetabular deformities considering the relatively low degree of deviation
200 from the target position.

201 In conclusion, 25 hips with severe acetabular deformities in 22 patients who underwent THA with a
202 CT-based navigation system were retrospectively reviewed and compared with mild dysplastic group.
203 There were no significant differences in accuracy of navigation system between two groups in terms of
204 three-dimensional component position and angle. The use of CT-based computer navigation helps the
205 surgeon to orient the acetabular component with minimal variation with regard to both component
206 position and angle in cases of severe pelvic deformity.

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Figure 1
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Figure 2
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Legend to Figures

Fig. 1.

Component position and angle were measured by superposition of CAD model of the acetabular component on the image of the actual implanted component.

Fig. 2.

Accuracy of the anteversion and inclination angles between preoperative planning and actual component position. The boundaries of the boxes indicate the 25th and 75th percentiles, and the lines within the boxes indicate the mean values. The whiskers above and below the boxes indicate the 90th and 10th percentiles.

Fig. 3.

(A) Preoperative anteroposterior radiograph of a 68-year-old woman with left arthrodesed hip and (B) postoperative radiograph at 1-year follow-up.

Fig. 4.

A 70-year-old woman with bilateral severe dislocated hip. (A) Preoperative and (B) postoperative anteroposterior radiographs at 8 (right) and 7-month (left) follow-up.

Table 1

1	Table 1. Patient demographic data of the two groups			
2	Patient characteristics	Study group (n=25)	Control group (n=25)	P-value
3	Age	62.8 ± 10.3 (36-81)	64.9 ± 10.0 (51-87)	0.686
4	Sex (female / male)	24 / 1	21 / 4	0.349
5	Side (left / right)	13 / 12	19 / 6	0.141
6	Height (cm)	149.3 ± 6.5 (137-163)	152.1 ± 6.6 (137-165)	0.614
7	Weight (kg)	56.0 ± 9.6 (38-75)	53.8 ± 10.7 (38-77)	0.733
8	Body mass index (kg/m²)	25.3 ± 5.0 (16.4-36.7)	23.1 ± 3.7 (18.5-30.2)	0.681
9	Diagnosis	Crowe III: 9	Crowe I: 18	
10		Crowe IV: 9	primary osteoarthritis: 7	
11		ankylosis: 3		
12		destructive arthritis: 1		
13		Charcot joint: 1		
14		arthrodesed hip: 1		
15	All values are means ± standard deviation (range).			

Table 2

1 **Table 2.** Results of mean deviation between preoperative planning and actual component position

2	Parameters	Study group (n=25)	Control group (n=25)	P-value
3	Horizontal position (mm)	3.2 ± 2.5 (0-9.7)	2.7 ± 2.3 (0-8.0)	0.719
4	Vertical position (mm)	3.4 ± 3.6 (0-15.0)	2.7 ± 1.7 (0.3-6.3)	0.696
5	Anteroposterior position (mm)	3.3 ± 2.3 (0-8.7)	2.7 ± 1.7 (0-6.3)	0.609

6 All values are means ± standard deviation (range).

Table 3

Table 3. Results of component angle

Parameters	Inclination		Anteversion	
	Study group	Control group	Study group	Control group
Preoperative planning (Pre)	40.0 ± 0.0 (40)	40.0 ± 0.0 (40)	20.0 ± 0.0 (20)	20.0 ± 0.0 (20)
Intraoperative record (Intra)	39.4 ± 1.4 (35-41)	39.0 ± 1.6 (37-43)	19.3 ± 2.0 (12-22)	19.4 ± 1.7 (17-24)
Postoperative measurement (Post)	39.5 ± 1.7 (36.3-43.0)	38.1 ± 1.8 (34.7-40.7)	17.5 ± 2.9 (10.3-22.3)	17.7 ± 2.9 (14.3-23.0)
Pre- Post	1.5 ± 1.2 (0-3.7)	2.0 ± 1.7 (0-5.3)	2.9 ± 1.8 (0.3-7.0)	3.2 ± 1.8 (0-5.7)
P-value	0.657		0.632	
Intra – Post	1.5 ± 1.2 (0-4.7)	1.4 ± 1.1 (0-4.3)	2.5 ± 1.7 (0-7.0)	2.7 ± 1.4 (0-5.7)
P-value	0.744		0.645	

All values are means ± standard deviation (range).

Table 4

1 **Table 4.** Results of component size and RMS analysis

2	Parameters	Study group (n=25)	Control group (n=25)	<i>P</i> -value
3	Accuracy of the component size	20 / 25 (80.0%)	22 / 25 (88.0%)	0.702
4	Error of RMS analysis (mm)	0.78 ± 0.21 (0.45-1.31)	0.87 ± 0.23 (0.51-1.53)	0.612

5 All values are means ± standard deviation (range).

6 RMS: root mean square