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ORIGINAL PAPER

The utility of digital templating in Total Hip Arthroplasty with Crowe type II and III dysplastic hips

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Abstract With the superiority of digital imaging, conventional preoperative acetate templating is gradually being replaced by digital templating in total hip arthroplasty (THA). The purpose of this study was to assess the utility of digital templating for patients with Crowe type II and III dysplastic hips. In this study, 41 THA patients with Crowe type II or III dysplastic hips and 48 THA patients with other primary diseases were retrospectively reviewed. All patients were fitted with cementless prostheses in 2008. For the THA patients with dysplastic hips, we attempted to restore their hip centres to the position of the true acetabulum. Digital templating was the method chosen to achieve hip centre restoration. The prosthesis prediction accuracy (within ± one size using digital templating) was 20 (48.8%) for the cup size and 30 (73.2%) for the stem size. Meanwhile, for patients with other primary diseases, the accuracy for the cup size within ± one size was 34 (70.8%) and for the stem size accuracy was within ± one size in 38 (79.2%). Between the two patient groups, there was a significant difference in the predicted cup size. In patients with dysplastic hips, the low accuracy of the predicted cup size may have resulted from difficulty in predicting the vertical location of the hip centre. Despite this limitation, preoperative planning using digital templating is a convenient technique for THA patients with Crowe type II and III dysplastic hips.

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Introduction

Preoperative template planning is an important step in achieving a successful outcome in THA. The traditional technique of preoperative planning is performed using acetate templating superimposed on printed radiographic films. With the development of digital images, this conventional technique is gradually becoming impractical because film-based radiographs may no longer exist. Some studies have reviewed the utility of a digital templating technique [3, 5, 9, 10, 12, 14, 19], but most of them focussed on comparison of the accuracy between acetate templating and digital templating [3, 9, 10, 12, 14, 19]. In most of these studies, the primary diagnosis of THA was osteoarthritis or was not specified (Table 1). However, it is uncertain whether digital templating is suitable for THA resulting from other primary diseases of severe deformity, such as hip dysplasia. To the best of our knowledge, few reports have studied the accuracy of digital templating in THA with regard to dysplastic hips.

The dysplastic hip has disturbed proximal femoral anatomy and a distorted acetabular shape [1] that makes THA technically demanding. In particular, a sloped acetabulum in Crowe type II or III [4] not only has severe bone loss, but also presents a challenge for positioning the implant cup at the proper location. Such difficulties predispose to failure of implanted components after operation. Therefore, compre-

Table 1 Published results of digital templating

Publication	Cases (*n*)	Type of prosthesis	Acetate templating (% within ± 1 size)		Digital templating (% within ± 1 size)		Primary diagnosis
			Cup	Stem	Cup	Stem	
Crooijmans et al. [3][a]	17	Cemented	89.7	97.1	36.8 80.9	55.9 94.1	Unspecified
	16	Uncemented	82.8	84.4	62.5 75	50 82.8	Unspecified
Davila et al. [5][b]	36	Unspecified			86	72	Unspecified
Gamble et al. [9]	40	Uncemented	60	85	80	85	Osteoarthritis
González Della Valle et al. [10][c]	64	Uncemented cup Cemented stem	97	 98	81	 94	Primary osteoarthritis
Iorio et al. [12]	50	Unspecified	78	77	60	74	Unspecified
Kosashvili et al. [14][d]	18	Uncemented	58 33	74 65	83 19	83 41	Primary osteoarthritis
The et al. [19]	112 61	Cemented Uncemented	73 64	89 52	72 52	79 66	Osteoarthritis

[a] Two methods of digital templating were used in the study, which were compared with acetate templating.

[b] Only digital templating was used in the study, which wasn't compared with acetate templating.

[c] The hybrid hip replacements were performed in the study. Uncemented cups and cemented stems were used.

[d] Two surgeons conducted preoperative templating independently in the study and their results were listed.

hensive preoperative planning is essential for these patients to avoid a high incidence of complications. Since standardised printed films are currently being replaced by digital images, we have attempted to assess the accuracy and reliability of digital templating in THA for Crowe type II and III dysplastic hips. The purpose of the study was to evaluate the utility of the preoperative digital templating method for complex THA surgery on Crowe type II and III dysplastic hips.

Materials and methods

THA procedures in our study were performed by one arthroplasty surgeon at our institution in 2008. All of the implants were cementless prostheses with a Secur-Fit HA stem and either an Osteonics Crossfire or an Osteonics ceramic acetabular cup (Stryker, Mahwah, NJ, USA). All preoperative and postoperative radiographs were obtained with a standardised 100-cm distance from the tube to the X-ray plate. Standardised radiographs included an anteroposterior (AP) view of the pelvis and an AP view and lateral view of the affected hip. The AP view of the pelvis contained the proximal third of both femurs. Cedara I-Reach™ software (Merge Healthcare, Milwaukee, WI, USA) was used for the digital Picture Archiving and Communication System (PACS), which included digital templating software.

Our study consisted of two parts. First, we determined the magnification of the digital images. Second, we determined the accuracy and reliability of digital templating for THA on patients with dysplastic hips.

Study part one

In the first part of the study, in order to determine the magnification of the digital images, we initially included a group of 25 cases of THA in a retrospective analysis, with 13 females and 12 males between 55 and 71 years of age. The actual sizes of the acetabulum cups were known from the operative records. The magnification was calculated as the ratio of the cup size measured on postoperative digital image relative to the actual cup size. The average magnification obtained from part one was applied to the patients in the second part of the study, while patients in part one were excluded.

Study part two

In the second part, to assess the method of digital templating, 41 cases of primary THA with dysplastic hips were retrospectively reviewed. The patient group included 35 patients (20 females and 15 males) between 49 and 65 years of age. The severity of the dislocation was evaluated according to the classification of Crowe et al. There were 23 cases of type II and 18 cases of type III dysplasia hips. We also established a control group of 48 cases of THA with other primary diagnoses. This group consisted of 44 patients (20 females and 24 males) between 55 and 79 years of age. There were 14 cases of fractures of the femur neck, 13 cases of femoral head

necrosis and 21 cases of primary osteoarthritis. Patients in part one were excluded from this part.

Digital templating

Before digital templating, the magnification of the digital images was adjusted to the value determined in part one. A combination of digital images and a digital template with identical magnification was available. The next step was to assign the teardrop on the AP view of the pelvis in digital images. The inter-teardrop line was drawn through the base of both teardrops as a reference. The vertical location of the hip centre was measured as the distance between the inter-teardrop line and the hip centre. The horizontal location was measured as the distance between the hip centre and a line through the teardrop, which was perpendicular to the inter-teardrop line (Fig. 1). Next, the digital template of the prosthesis was superimposed on the AP pelvic view in the digital images. The desired location of the hip prosthesis centre was matched to the contralateral hip, if normal (Fig. 1). When the contralateral hip was also dysplastic, the teardrop was selected as a landmark to position the cup. The inferior portion of the cup was positioned at the level of the teardrop, and its surface was beyond Kohler's line with an abduction angle of 40–45°. The selected cup size was that which best fit the acetabulum while requiring a minimal amount of bone to be reamed (Fig. 2). If the cup did not acquire adequate coverage in the superolateral roof, bone grafts were planned for cup coverage (Figs. 1 and 2). In comparison to the prediction of the cup size, the preoperative template planning of the femoral stem was relatively simple. The femoral stem that matched both the intramedullary canal and the proximal femoral metaphysis was selected, assuming that the femoral neck cut would be less than 1 cm proximal to the lesser trochanter (Fig. 3).

Surgical procedure

The operations were performed via a posterolateral approach to the hip. For a sloped acetabulum in type II or III dysplasia, special attention had to be paid to the acetabular reconstruction to avoid incorrect placement of the acetabular component in a lateralised position. This error was avoided by initial medialisation by first using smaller reamers at the position of the true acetabulum, followed by progressively larger reamers to enlarge the periphery of the acetabular bed. The true acetabulum was identified, as its inferior portion was the inferior portion of the sloped acetabulum after the marginal osteophyte was cleaned. If there was still a superolateral bone defect after reaming the acetabulum deep and wide, superolateral screws were used for further cup fixation. Then, the bone defect between the cup and the acetabular roof was filled with impacted morsellised bone grafts from the autogenously resected femoral head. After acetabular construction, the femoral neck was osteotomised less than 1 cm proximal to the lesser trochanter. The size of the femoral stem was deemed appropriate when the surgeon felt a sensation of tightness between the last reamer and the medullary canal.

Statistical analysis

All of the measurements were taken by an investigator independent from the operating staff. The following data were collected during the study: (1) the planned component size, (2) the actual component size, (3) the predicted location of the hip centre, (4) the location of the postoperative hip centre, and (5) the preoperative and six-months postoperative clinical function by Harris hip score.

Agreement of the planned components was defined in our study as being within one size. Coincidence rates were calculated based on the predicted and the actual sizes of the implants. The chi-square test was performed to determine

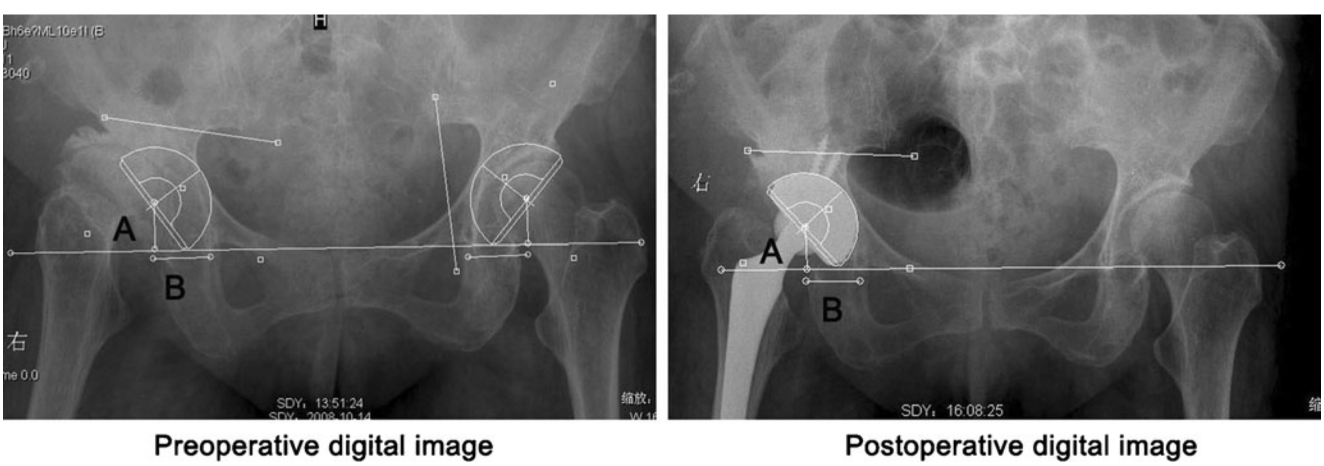

Fig. 1 The normal contralateral hip was used as a reference to predict the hip centre of the dysplastic hip. The bone defects in the superlateral roof were filled with impacted bone grafts. (**a**) The vertical location of the hip centre. (**b**) The horizontal location of the hip centre

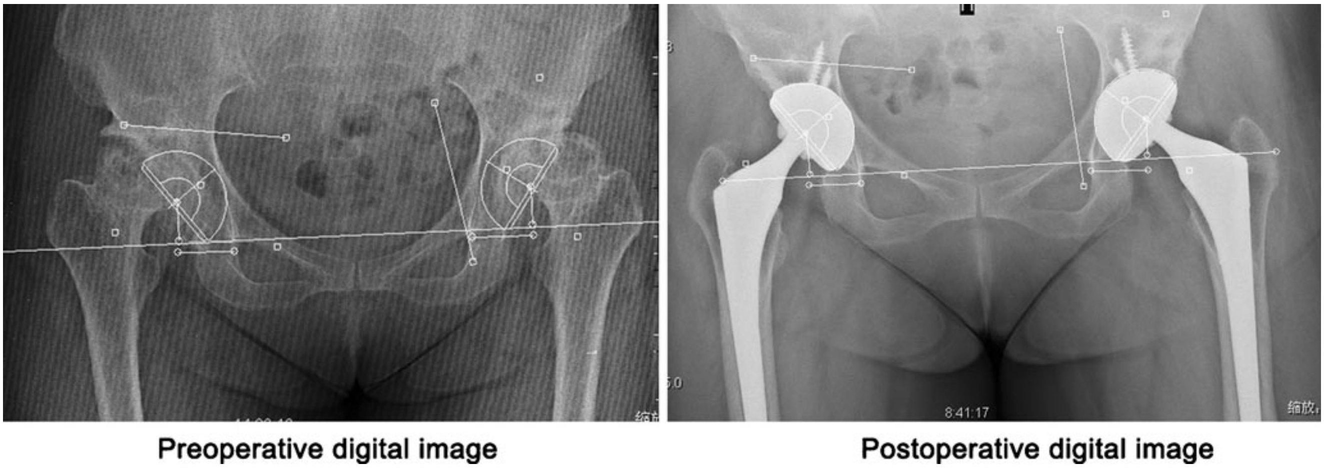

Fig. 2 When both hips were dysplastic, the teardrop was selected as a landmark to position the cup. The surface of the cup protruded beyond the Kohler line according to the medialisation of the cup. The inferior portion of the cup was positioned at the level of the teardrop

the differences in the coincidence rates between the two groups. The paired t-test was used for comparison between the predicted and postoperative locations of the hip centre. To assess the intraobserver reliability of the predicted implant's size, preoperative radiographs for each patient were templated by one investigator, who repeated templating three weeks later. To assess interobserver reliability, templating of preoperative radiographs was repeated by another investigator independently. Intraobserver and interobserver effects were calculated using an intraclass correlation coefficient (ICC). All statistical analyses were performed using SPSS version 10. For all statistical tests, we considered $p < 0.05$ to be significant. ICC was interpreted as follows: from 0 to 0.2 indicated poor agreement, from 0.3 to 0.4 indicated fair agreement, from 0.5 to 0.6 indicated moderate agreement, from 0.7 to 0.8 indicated strong agreement, and greater than 0.8 indicated almost perfect agreement.

Results

Magnification of the digital images

From the first part of the study, the mean value and standard deviation of the magnifications was 123±4%.

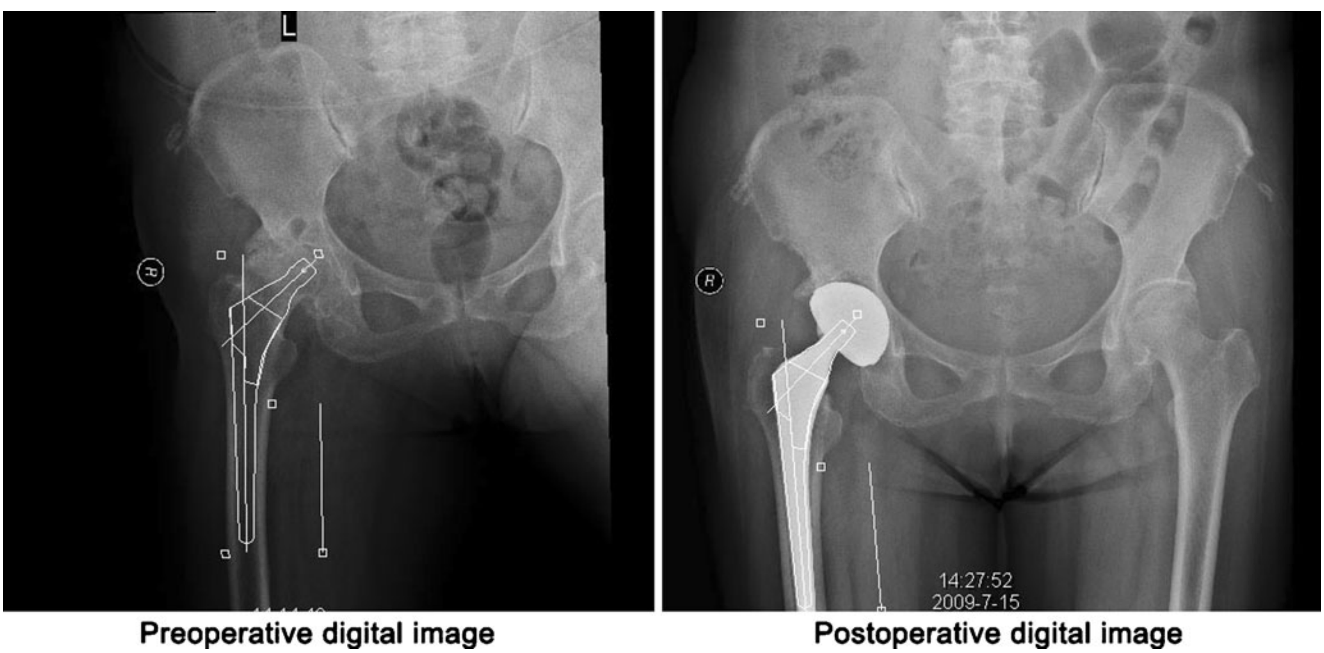

Fig. 3 In the digital templating of the femoral stem, it was assumed that the femoral neck cut was less than 1 cm proximal to the lesser trochanter. The selected femoral stem was the one that matched both the intramedullary canal and the proximal femoral metaphysis

Table 2 Predictability of prosthesis size

Disease	Cases (*n*)	Cup (with ± 1 size)	Stem (with ± 1 size)
Hip dysplasia	41	20 (48.8%)[a]	30 (73.2%)
Other primary disease	48	34 (70.8%)	38 (79.2%)

[a] Compared with the cup size for other primary diseases, $p<0.05$ (chi-square test)

Predictability of the prosthesis size

The results of the prosthesis size predictability are shown in Table 2. The predictability of the cup size in patients with dysplastic hips was significantly lower than that of the control group. There was no significant difference in the predictability of the stem size between the two groups. The size difference between templated and implanted prosthesis components is shown in Fig. 4. Notably, the curve of the differences in cup size was more decentralised in the group with dysplastic hips.

Predictability of the hip centre

The results of the predicted and postoperative location of the hip centre are shown in Table 3. In the control group, there was no significant difference in the predicted and postoperative location of the hip centre, which showed an excellent level of predictability for the hip centre. In the group with dysplastic hips, there was no significant difference in the horizontal location, but the vertical location of the postoperative hip centre was significantly different from the predicted value.

Reliability of the predicted implant's size

The results are shown in Table 4. The intraobserver reliability for the cup size and the stem size in the dysplastic hip group using ICC are 0.76 and 0.83, respectively. The ICCs for the cup and stem sizes in the group with other diseases are 0.93 and 0.92, respectively. The repeated measurements were also analysed to assess interobserver reproducibility. In the dysplastic hip group, the ICC was 0.80 for the acetabulum and 0.90 for the stem. In the group with other diseases, the ICC was 0.90 for the acetabulum and 0.94 for the femoral stem.

Clinical function

In the dysplastic hip group, the mean Harris hip score improved from 45 points preoperative to 89 points

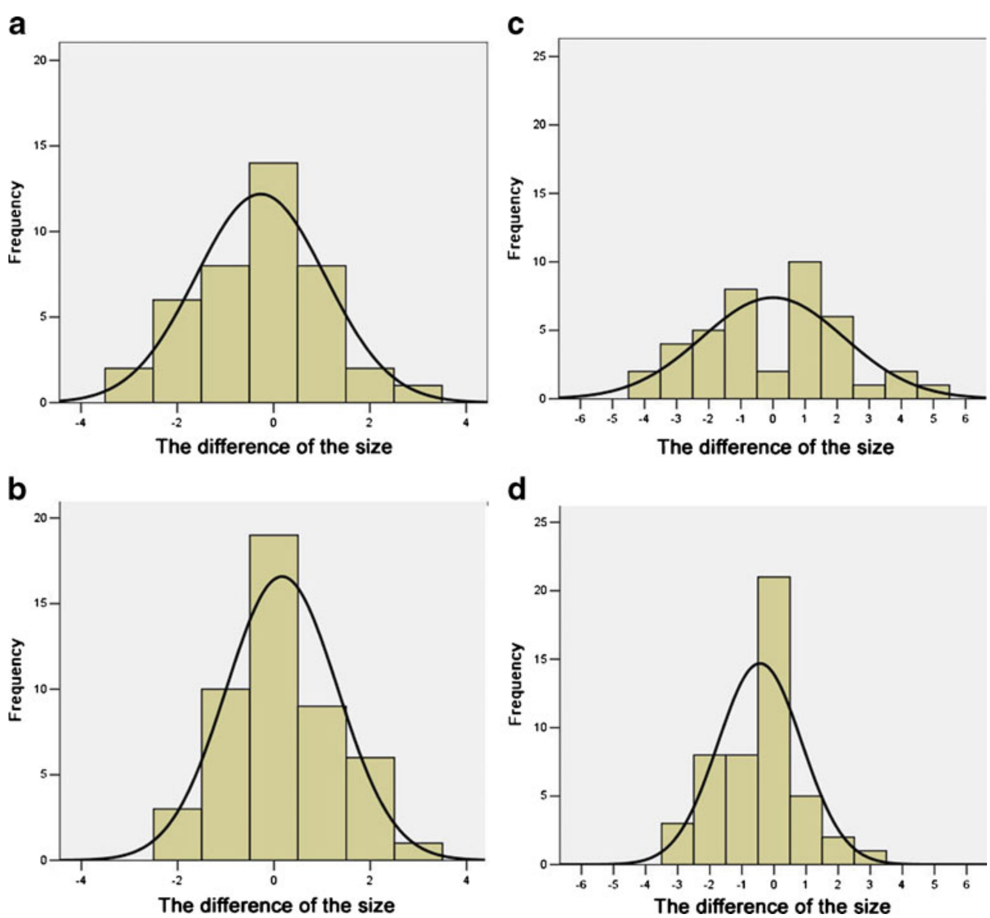

Fig. 4 Histograms and corresponding curves showed the size differences between the templated and implanted prosthesis components: the difference of the stem size in the group with dysplastic hips (**a**), the difference of the stem size in the control group (**b**), the difference of the cup size in the group with dysplastic hips (**c**), and the difference of the cup size in the control group (**d**)

Table 3 Predicted and postoperative location of the hip centre (mean ± standard deviation)

Disease	Location	Predicted location (mm)	Postoperative location (mm)	Difference
Hip dysplasia	VL	20.6±4.02[a]	18.7±4.06	1.95±4.50
	HL	27.3±3.93	26.7 ± 2.77	0.61 ± 3.45
Other primary disease	VL	18.3±3.86	17.7±3.86	0.57±3.76
	HL	29.1 ± 3.51	28.6±3.12	0.53±3.31

VL vertical location, *HL* horizontal location

[a] Compared with the postoperative location, $p<0.05$ (paired t-test)

postoperative six months after operation. Meanwhile, for the patients with other primary diseases, the mean Harris hip score improved from preoperative 57 points to 93 points six months after operation.

Discussion

The results show that the templating technique had good reliability, with all ICC values greater than 0.7. There was low accuracy of predicted cup size in patients with dysplastic hips, compared to patients with other primary diseases. All patients had satisfactory clinical results six months after operation in the two groups. In part one of our study, the mean value and standard deviation of the magnifications was measured as 123±4%. We therefore assumed an average magnification value of 123% for part two of the study. Using the magnification of 120±6% reported in the literature, Unnanuntana et al. found that when acetate templating was used, predictability of the cup size was much poorer than that for the femoral component. According to the authors, one of the factors explaining this reduced accuracy was that 62.4% of the patients in the series had dysplastic hips [20]. To date, there have been few reports in the literature on the accuracy and reliability of digital templating in THA patients with dysplastic hips.

THA is technically demanding in patients with dysplastic hips, especially the acetabular reconstruction; however, combining medialisation or proximalisation of the acetabular cup with various techniques for superolateral bone grafting can be helpful during total hip replacement for patients with dysplastic hips [6, 7, 17]. Bicanic et al. reported that hip load decreased when the cup was placed more medially or distally in THA in patients with dysplastic hips [2]. In our study, we employed the method of medialisation of the hip centre by deeply reaming the medial wall at the level of the true acetabulum. The true acetabulum was identified by the location of its inferior portion after the marginal osteophyte was cleared. The postoperative radiographs showed that the mean location of the hip centre was 26.7 ± 2.77 mm horizontally and 18.7±4.06 mm vertically, which are more accurate than those reported for other studies [8, 11]. Proper positioning of the hip centre prevents the acetabular component from loosening. Concerning loosening of the femoral stem, most reports have documented good survival rates in patients with dysplastic hips [13, 16]. Because dysplastic hips have various degrees of hip dislocation, we osteotomised the femoral neck less than 1 cm proximal to the lesser trochanter in order to minimise the tension on the reconstructed hip. With this surgical technique, there were good clinical results for patients with dysplastic hips at an average of 5.2 years, following-up another report [21].

In this study, most of the details of digital templating were similar to the method described in the literature [9, 10]. The difference depended on the principles of the reconstructed hip, as mentioned above. The medialisation of the hip centre caused the cup to protrude beyond the Kohler line, as seen in postoperative radiographs. Therefore, the planning cup was positioned medially beyond the Kohler line in digital templating. In the literature, the Kohler line was always defined as the medial border of the cup in digital templating [9, 10]. In digital templating of the femoral stem, it was assumed that the femoral neck cut was less than 1 cm proximal to the lesser trochanter, which was about 1 cm proximal to the lesser trochanter in the literature [9].

Our results show that the predictability of THA in patients with dysplastic hips was 48.8% for cup size and 73.2% for stem size. The curve of the differences in cup size was more decentralised in the group with dysplastic hips in Fig. 4. Although the anatomical deformity of the acetabulum and proximal femur both affected the preoper-

Table 4 Reliability of the predicted implant size

Disease	Location	Intraobserver reliability	Interobserver reliability
Hip dysplasia	Cup	0.76	0.80
	Stem	0.83	0.90
Other primary disease	Cup	0.93	0.90
	Stem	0.92	0.90

ative templating of the dysplastic hips, only the predictability of the cup size was significantly lower than that of the control group. Selections of the component's size were mostly dependent on its location. In our preoperative templating, the teardrop was assigned as a reference to locate the planning cup and the true acetabulum. Using this method, the predictability of the planning cup was 80–81% in previous studies [9, 10]. In our surgical procedure, the inferior portion of the true acetabulum was identified as the location of the inferior portion of the sloped acetabulum after the marginal osteophyte was cleared. However, it was difficult to identify the true acetabulum during both preoperative templating and surgery because of the sloped shape of the deformed acetabulum. Despite attempting to place all components in the true acetabulum, the acetabula analysed by Stans et al. [18] were placed outside the true acetabular region in 25.7% of Crowe type III dysplastic hips compared with 12% in Crowe type II [15]. On the other hand, the deformity of the proximal femur always appeared excessively narrow. This presentation had little effect on our judgement of the proper place at which to position the stem. Hence, the predictability of the cup size was more affected than that of the stem size in the preoperative templating of dysplastic hips.

In addition, the low accuracy of the prediction for cup size meant that the predicted hip centre was also low in the group of dysplastic hips. However, the results showed that the predicted and postoperative hip centres were significantly different only in the vertical direction. The predicted hip centre was higher than the postoperative hip centre in the vertical direction (Table 3). This finding suggests that reconstruction of the cup was accomplished strictly via medialisation both in preoperative planning and during the operation. The discrepancy between the predicted cup and the actual cup may have resulted from an inaccurate prediction of the hip centre's vertical location.

In conclusion, the predictability of the cup size was much lower than that of the femoral component for patients with dysplastic hips. The accuracy of the predicted cup size has only 48.8% accuracy within ± one size using digital templating. This low accuracy may have resulted from difficulty in predicting the vertical location of the hip centre. However, PACS combined with digital templating offers economic benefits to hospitals and patients by decreasing the cost of image production and film storage. Use of the digital templating software enclosed with PACS is simple and straightforward for surgeons. Therefore, digital templating is a low cost and convenient technique for patients with dysplastic hips undergoing THA.

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Conflict of interest statement The authors state that there is no conflict of interest.

References

1. Argenson JN, Flecher X, Parratte S, Aubaniac JM, Jean-Noel A (2007) Anatomy of the dysplastic hip and consequences for total hip arthroplasty. Clin Orthop Relat Res 465:40–45
2. Bicanic G, Delimar D, Delimar M, Pecina M (2009) Influence of the acetabular cup position on hip load during arthroplasty in hip dysplasia. Int Orthop 33(2):397–402
3. Crooijmans HJ, Laumen AM, van Pul C, van Mourik JB (2009) A new digital preoperative planning method for total hip arthroplasties. Clin Orthop Relat Res 467:909–916
4. Crowe JF, Mani VJ, Ranawat CS (1979) Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am 61(1):15–23
5. Davila JA, Kransdorf MJ, Duffy GP (2006) Surgical planning of total hip arthroplasty: accuracy of computer-assisted EndoMap software in predicting component size. Skeletal Radiol 35:390–393
6. Delimar D, Cicak N, Klobucar H, Pecina M, Korzinek K (2002) Acetabular roof reconstruction with pedicled iliac graft. Int Orthop 26:344–348
7. Dorr LD, Tawakkol S, Moorthy M, Long W, Wan Z (1999) Medial protrusio technique for placement of a porous-coated, hemispherical acetabular component without cement in a total hip arthroplasty in patients who have acetabular dysplasia. J Bone Joint Surg Am 81(1):83–92
8. Flecher X, Parratte S, Brassart N, Aubaniac JM, Argenson JN (2008) Evaluation of the hip center in total hip arthroplasty for old developmental dysplasia. J Arthroplasty 23(8):1189–1196
9. Gamble P, de Beer J, Petruccelli D, Winemaker M (2009) The accuracy of digital templating in uncemented total hip arthroplasty. J Arthroplasty. doi:10.1016/j.arth.2009.04.011
10. González Della Valle A, Comba F, Taveras N, Salvati EA (2008) The utility and precision of analogue and digital preoperative planning for total hip arthroplasty. Int Orthop 32:289–294
11. Hirakawa K, Mitsugi N, Koshino T, Saito T, Hirasawa Y, Kubo T (2001) Effect of acetabular cup position and orientation in cemented total hip arthroplasty. Clin Orthop Relat Res 388:135–142
12. Iorio R, Siegel J, Specht LM, Tilzey JF, Hartman A, Healy WL (2009) A comparison of acetate vs digital templating for preoperative planning of total hip arthroplasty: is digital templating accurate and safe? J Arthroplasty 24(2):175–179
13. Kim YH, Kim JS (2005) Total hip arthroplasty in adult patients who had developmental dysplasia of the hip. J Arthroplasty 20:1029–1036
14. Kosashvili Y, Shasha N, Olschewski E, Safir O, White L, Gross A, Backstein D (2009) Digital versus conventional templating techniques in preoperative planning for total hip arthroplasty. Can J Surg 52(1):6–11
15. Pagnano W, Hanssen AD, Lewallen DG, Shaughnessy WJ (1996) The effect of superior placement of the acetabular component on the rate of loosening after total hip arthroplasty. J Bone Joint Surg Am 78(7):1004–1014
16. Papachristou G, Hatzigrigoris P, Panousis K, Plessas S, Sourlas J, Levidiotis C, Chronopoulos E (2006) Total hip arthroplasty for developmental hip dysplasia. Int Orthop 30:21–25
17. Somford MP, Bolder SB, Gardeniers JW, Slooff TJ, Schreurs BW (2008) Favorable survival of acetabular reconstruction with bone impaction grafting in dysplastic hips. Clin Orthop Relat Res 466 (2):359–365

18. Stans AA, Pagnano MW, Shaughnessy WJ, Hanssen AD (1998) Results of total hip arthroplasty for Crowe 3 type developmental hip dysplasia. Clin Orthop Relat Res 348:149–157
19. The B, Diercks RL, van Ooijen PM, van Horn JR (2005) Comparison of analog and digital preoperative planning in total hip and knee arthroplasties. Acta Orthop 76(1):78–84
20. Unnanuntana A, Wagner D, Goodman SB (2009) The accuracy of preoperative templating in cementless total hip arthroplasty. J Arthroplasty 24(2):180–186
21. Zhen'an Z, Kerong D, Yuehua S, Jian T, You W, Yongqiang C, Dingwei S (2004) Total hip replacement for congenital hip dysplasia. Shanghai Medical Journal 27(2):81–82