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Original Article

Validity and application of Doiguchi's pelvic tilt measurement method

Manabu Tsukamoto [a], Makoto Kawasaki [a, *], Takayuki Nabeshima [a], Hitoshi Suzuki [a], Teruaki Fujitani [a], Ko Chiba [b], Yuichi Doiguchi [c], Makoto Osaki [b], Akinori Sakai [a]

[a] Department of Orthopaedic Surgery, School of Medicine, University of Occupational and Environmental Health, Kitakyushu, Japan
[b] Department of Orthopedic Surgery, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan
[c] Masuda Orthopaedic Clinic, Sasebo, Japan

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ABSTRACT

Background: The validity of Doiguchi's pelvic tilt measurement method has not been proven. The objective in our study was to validate the method.
Methods: Our investigation included 73 total hip arthroplasties (THAs) performed using our cup placement procedure from July 2020 to November 2021. Pelvic tilt formed by the pubic symphysis and sacral promontory (PT_{PS}) in supine and lateral positions was calculated by two methods (the Doiguchi method and the digital reconstructed radiograph (DRR) method using a 3D computer templating system) based on the transverse and longitudinal diameters of the pelvic ring measured immediately before THA.
Results: There was a strong/moderate correlation in the values of PT_{PS} between the Doiguchi and DRR methods. However, the value of PT_{PS} calculated by the Doiguchi method was significantly lower than that calculated by DRR, and there was a partially direct match. On the other hand, there was no significant difference in the value of PT change from supine to lateral position between the Doiguchi and DRR methods. The PT changes based on both methods were strongly correlated, and the PT change calculated by the Doiguchi method was almost identical to that calculated by the DRR method.
Conclusions: Doiguchi's pelvic tilt measurement method was validated for the first time. These results demonstrated that the ratio of the transverse and longitudinal diameters of the pelvic ring was an important factor defining the change in pelvic tilt. The slope in the linear function of the Doiguchi method was found to be almost the correct value, although the intercept of the linear function exhibited individual differences.

1. Introduction

Total hip arthroplasty (THA) is a procedure that is performed in over 60,000 cases per year in Japan [1]. Suitable implant placement is an important factor in the long-term outcome of THA, especially in cup placement, where both aspects of mechanical durability and dislocation resistance must be achieved. Since the cup placement angle is defined by the pelvic coordinate system, it is important to grasp the tilt of the anatomical pelvic plane (APP), an anatomical landmark of the pelvis, preoperatively and intraoperatively [2,3]. In Japan, more than 50% of patients undergo THA in the lateral decubitus position [1]. Since the orientation of the APP when the patient is placed in the lateral decubitus position is unclear, it is difficult to set the pelvic coordinate system during THA in the lateral decubitus position [4]. Although the pelvic tilt and cup placement angle are often confirmed preoperatively and intraoperatively using X-rays, even when we have such confirmation, it is difficult to ascertain the orientation of the pelvis and cup.

Although there are several methods for measuring pelvic tilt using anteroposterior X-ray images of the hip [5], the Doiguchi method was published in 1992 and is the oldest method used in Japan [6]. Based on the ratio of the longitudinal and transverse diameters of the pelvic ring, a formula for determining the pelvic tilt relative to the film plane has been established for each sex, but there are no reports examining the validity of this method.

We have devised a procedure for accurate cup placement during THA in the lateral decubitus position using the Doiguchi method [7]. In our procedure, the pelvic tilt angle relative to the film plane in the supine and lateral positions was measured using the

* Corresponding author. Department of Orthopaedic Surgery, School of Medicine, University of Occupational and Environmental Health, 1-1 Iseigaoka, Yahatanishi-ku, Kitakyushu, 807-8555, Japan.
E-mail address: k-makoto@med.uoeh-u.ac.jp (M. Kawasaki).

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Doiguchi method to capture changes in pelvic tilt relative to the film plane, and these changes were used to correct the target angle of the cup using formulas composed of trigonometric functions [8]. Although we reported that our procedure contributed to improving the accuracy of cup placement by measuring cup orientation on CT images [8], in practice, the validity of the Doiguchi method, which constitutes our procedure, has not been demonstrated.

The objectives of our study were 1) to validate the method of Doiguchi's pelvic tilt measurement published in 1992 and 2) to prove the validity of using the Doiguchi method for our cup placement procedure by verifying the accuracy of the change in pelvic tilt relative to the film plane when the body position is changed from supine to lateral.

2. Materials and methods

2.1. Patients

This research was approved by the Institutional Review Board of the authors' affiliated institutions. The period of our investigation was from July 2020 to November 2021, and the investigation included 73 cases of THA that were performed using our cup placement procedure [8]. The study participants signed appropriate written consent forms after the study purpose was explained and discussed and then underwent THA using our cup replacement procedure. All patients underwent preoperative CT scans in the supine position. Fixation of the pelvis in the lateral decubitus position was performed by the positioner when patients underwent THA, and then a film plane was held parallel to the direction of the trunk on the operating table (TPP; table parallel plane), and anteroposterior radiographs (TPP images) were taken of the pelvis with the patient in the lateral decubitus position and the X-ray beam centered on the pubis symphysis.

2.2. Doiguchi method

Anteroposterior and lateral radiographs of 10 cadaveric pelvic specimens were taken simultaneously at seven different sagittal tilt angles in Doiguchi et al.'s study, and the formula was based on the above data [6]. The value of the longitudinal diameter of the pelvic foramen (L) divided by the horizontal diameter of the pelvic foramen (T) (L/T ratio) is determined by taking measurements on the anteroposterior radiographs of the pelvis; the observed dimensions are entered into the formula based on the L/T ratio [6].

In all cases, the T and L diameters of the pelvic foramen on CT scout view in the supine position and X-rays in the lateral decubitus position were measured immediately before THA using the software program Image VINUS Web (Yokogawa Electronics Inc., Tokyo, Japan) [8–10] (Supplementary Fig. 1). Since we previously presented the intra/interobserver coefficient correlations and the measurements were in substantial agreement [7], the Doiguchi method was performed by each operator for the surgery. Based on the above measurements by each operator, the pelvic tilt formed by the pubic symphysis and sacral promontory (PT_{PS}) in the supine position, the PT_{PS} in the lateral decubitus position, and the change in pelvic tilt (PT change) relative to the film plane when changing position from supine to lateral were determined (Doiguchi method) (Fig. 1).

2.3. DRR method

Next, the xz-plane of the digital reconstructed radiograph (DRR) image using ZedHip (LEXI Co., Ltd., Tokyo, Japan) in the supine and lateral positions was rotated in 0.5-degree increments around the x-coordinate axis until matching the L/T ratio of the pelvic foramen measured by the Doiguchi method with the CT scout view in the supine position and the anteroposterior radiograph in the lateral decubitus position, respectively. Keeping the coordinate system fixed when the L/T ratio was matched, the vz-plane of the DRR image was created in the supine and lateral positions, and then, PT_{PS} in the supine position, PT_{PS} in the lateral decubitus position, and the PT change relative to the film plane when changing position from supine to lateral were determined (DRR method) (Fig. 1). Regarding the intra/interobserver reliability of the DRR method for 10 subjects selected randomly, the intraclass correlation coefficient (2, 1) for the PT change was 0.984 (95% confidence interval [CI], 0.938–0.996); thus, the DRR method was performed by one investigator.

2.4. Statistical analysis

The results related to the continuous variables are presented as the means ± SDs. The Shapiro–Wilk test was used to determine whether the variables followed a standard normal distribution. A paired *t*-test was used to indicate the differences in continuous variables between the Doiguchi and DRR methods. Between-variable associations were analyzed using the Pearson correlation coefficient. P values < 0.05 were considered indicative of statistical significance. A priori, a sample size calculation in the correlation analysis was performed with a power of 0.8, effect size of 0.7, and significance level of 0.05, and we confirmed that the number of patients required was 14. Since we planned to analyze men and women separately, we set the period of investigation so that at least 14 patients of each sex could be enrolled. All statistical analyses were performed using STATA/IC 16 (StataCorp, College Station, TX, USA).

3. Results

3.1. Characteristics

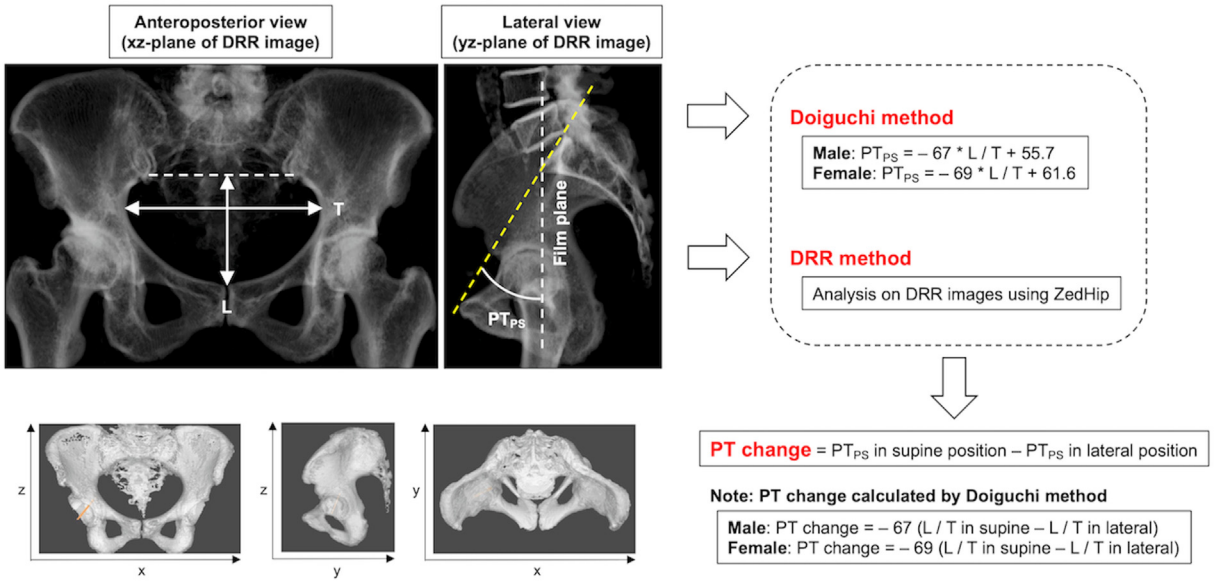
The demographic data are shown in Table 1. Seventy-three patients who underwent THA using our cup placement procedure were included in our investigation, and we were able to enroll a sufficient number of male/female patients for correlation analysis. The forward pelvic tilt was defined as positive, and the pelvic tilt of the APP in the supine position measured by ZedHip was 1.9° ± 8.0° (range; −23.4 to 15.3) (Fig. 2).

3.2. PT_{PS} in the supine position (Fig. 2)

PT_{PS} was calculated by the Doiguchi and DRR methods based on the L/T ratio measured from CT scout view images taken in the supine position before surgery. The value of PT_{PS} calculated by the Doiguchi method was significantly lower than that calculated by the DRR method ($p < 0.001$; mean − 8.83°; SD 5.9; 95% CI -10.2 to −7.4) (Table 2). The PT_{PS} based on both methods in all patients was strongly correlated ($r = 0.749$, $p < 0.001$), and there was a moderate positive correlation in males ($r = 0.555$, $p = 0.032$) and a strong positive correlation in females ($r = 0.780$, $p < 0.001$) between the Doiguchi and DRR methods. However, the PT_{PS} calculated by the Doiguchi method did not always match the PT_{PS} calculated by the DRR method (Fig. 2).

3.3. PT_{PS} in the lateral positions (Fig. 3)

PT_{PS} was calculated by the Doiguchi and DRR methods based on the L/T ratio measured from X-rays taken in the lateral decubitus position preoperatively. The value of PT_{PS} calculated by the Doiguchi method was significantly lower than that calculated by the



Note: PT_{PS}, pelvic tilt formed by the pubic symphysis and sacral promontory; PT change, change in pelvic tilt; DRR, digital reconstructed radiograph.

Fig. 1. Methodology of pelvic tilt measurement. Based on the measurements in Supplementary Fig. 1, PT_{PS} in the supine position, PT_{PS} in the lateral position, and the PT change from supine to lateral position were determined using the Doiguchi and DRR methods.

Table 1
Demographic characteristics.

Variable	All sexes (N = 73)	Male (N = 15)	Female (N = 58)
Age, y	67.1 ± 11.2 (44 to 87)	64.3 ± 13.5 (44 to 79)	67.8 ± 10.6 (45 to 87)
Height, cm	154.1 ± 8.4 (134 to 172)	165.3 ± 6.4 (155 to 172)	151.2 ± 5.0 (134 to 169)
Weight, kg	58.4 ± 11.9 (40 to 91)	68.9 ± 11.6 (56 to 88)	55.6 ± 10.4 (40 to 91)
Body mass index, kg/m^2	24.5 ± 4.1 (18.5 to 36.4)	25.2 ± 3.6 (20.1 to 30.5)	24.3 ± 4.2 (18.5 to 36.4)
Diagnosis, n (%)			
Osteoarthritis	58 (79.5)	6 (40.0)	52 (89.7)
Avascular necrosis	15 (20.5)	9 (60.0)	6 (10.3)

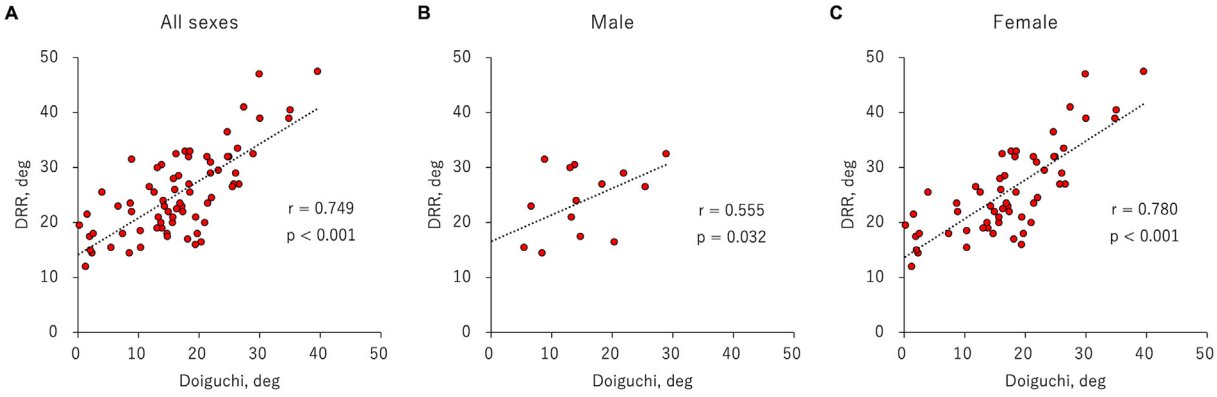


Fig. 2. PT_{PS} in the supine position calculated by Doiguchi and DRR methods. Scatter diagrams for (A) all sexes, (B) males and (C) females are shown. There were strong/moderate correlations between the Doiguchi and DRR methods. DRR, digital reconstructed radiograph.

DRR method ($p < 0.001$; mean −8.81°; SD 6.0; 95% CI -10.2 to −7.4) (Table 2). As with the PT_{PS} in the supine position, the PT_{PS} in the lateral decubitus position based on both methods was moderately correlated ($r = 0.664$, $p < 0.001$), and there was also a moderate positive correlation in males ($r = 0.579$, $p = 0.024$) and females ($r = 0.669$, $p < 0.001$) between the Doiguchi and DRR methods. However, the PT_{PS} calculated by the Doiguchi method did not always match the PT_{PS} calculated by the DRR method (Fig. 3).

3.4. PT change from the supine to lateral position (Fig. 4)

PT change from supine to lateral position was calculated using the Doiguchi and DRR methods, respectively. There was no significant difference in the PT change between the Doiguchi and DRR methods ($p = 0.759$; mean − 0.03°; SD 0.73; 95% CI -0.2 to 0.1) (Table 2). Since the PT changes based on both methods were strongly correlated ($r = 0.992$, $p < 0.001$), the PT change calculated

Table 2
Pelvic tilt parameters.

Variable	All sexes (N = 73)	Male (N = 15)	Female (N = 58)
PT_{APP} in supine position, deg	1.9 ± 8.0 (−23.4 to 15.3)	1.4 ± 7.4 (−13.9 to 10.9)	2.0 ± 8.3 (−23.4 to 15.3)
PT_{PS} in supine position, deg			
Doiguchi method	16.4 ± 8.7 (−0.4 to 39.5)	14.2 ± 7.9 (−0.4 to 28.9)	17.0 ± 8.9 (0.2 to 39.5)
DRR method	25.3 ± 7.8 (12.0 to 47.5)	23.5 ± 6.8 (12.0 to 32.5)	25.8 ± 8.0 (12.0 to 47.5)
P value[a]	<0.001	<0.001	<0.001
PT_{PS} in lateral position, deg			
Doiguchi method	16.3 ± 7.5 (1.9 to 37.9)	13.1 ± 8.3 (1.9 to 31.9)	17.1 ± 7.2 (2.0 to 37.9)
DRR method	25.1 ± 7.0 (7.5 to 46.5)	22.1 ± 7.2 (7.5 to 35.0)	25.8 ± 6.8 (13.5 to 46.5)
P value[a]	<0.001	<0.001	<0.001
PT change from supine to lateral position, deg			
Doiguchi method	0.19 ± 4.9 (−13.0 to 12.5)	1.06 ± 4.3 (−10.3 to 7.6)	−0.04 ± 5.1 (−13.0 to 12.5)
DRR method	0.21 ± 5.3 (−13.0 to 12.5)	1.27 ± 4.6 (−11.0 to 8.0)	−0.06 ± 5.4 (−13.0 to 12.5)
P value[a]	0.759	0.152	0.841

[a] Comparisons were performed using the Paired *t*-test. The results representing the continuous variables are presented as the means ± standard deviations with ranges in parentheses. PT_{APP}, pelvic tilt of the anatomic pelvic plane in the supine position; PT_{PS}, pelvic tilt formed by pubic symphysis and sacral promontory; PT change, change of pelvic tilt; DRR, digital reconstructed radiograph.

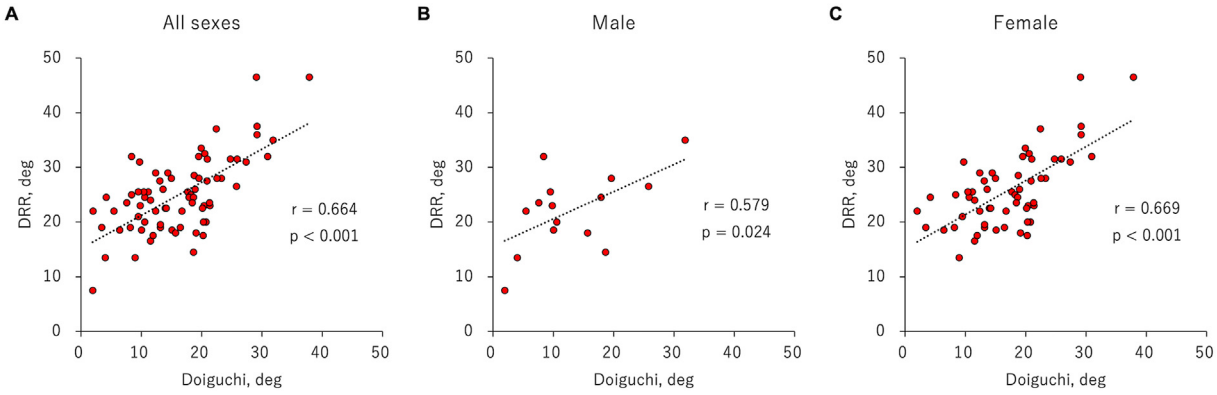


Fig. 3. PT_{PS} in the lateral position calculated by the Doiguchi and DRR methods. Scatter diagrams for (A) all sexes, (B) males and (C) females are shown. There were moderate correlations between the Doiguchi and DRR methods. DRR, digital reconstructed radiograph.

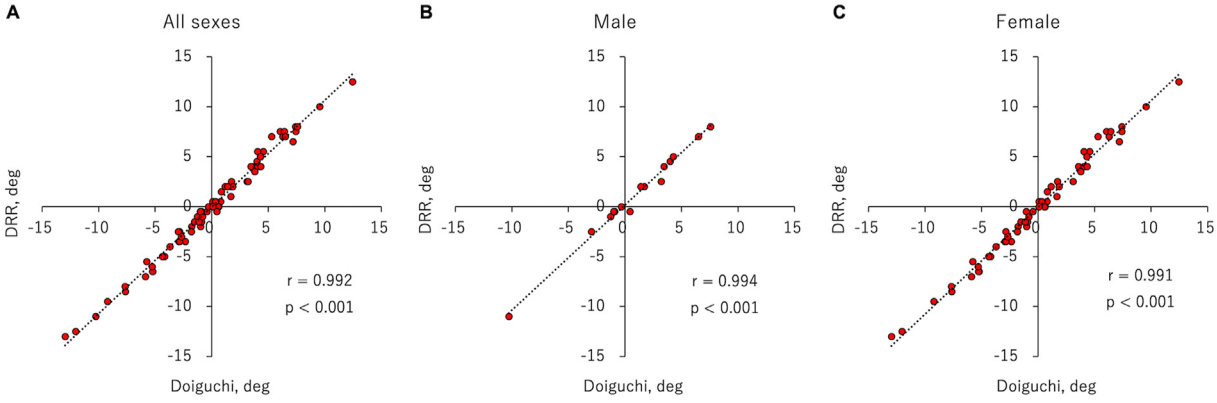


Fig. 4. PT change from the supine to lateral position calculated by Doiguchi and DRR methods. Scatter diagrams for (A) all sexes, (B) males and (C) females are shown. There were strong correlations between the Doiguchi and DRR methods. DRR, digital reconstructed radiograph.

by the Doiguchi method was almost identical to the PT change calculated by the DRR method, and thus, the PT change calculated by the Doiguchi method was close to the correct value.

4. Discussion

The Doiguchi method, one of the popular pelvic tilt measurement methods in Japan, has now been validated for the first time in our study. Patients who participated in a previous study of THA using a unique cup placement procedure were included in our study; the validity of the Doiguchi method was verified by calculating pelvic tilt using the Doiguchi and DRR methods based on the L/T ratio of the pelvic foramen, which was measured before the THA procedure. PT_{PS} in the supine and lateral positions calculated by the Doiguchi method showed moderate correlation with those calculated by the DRR method. Pelvic tilt changes from the supine to lateral position were strongly correlated between the Doiguchi and DRR methods, and the values calculated by each method were

almost identical. These results indicate that Doiguchi's formula is almost accurate for the slope of the linear function, although the intercept of the linear function varies from person to person. A discussion follows.

The formula by Doiguchi et al. was first reported in Japan in 1992 and was based on findings from each of five male/female cadaveric pelvic specimens [6]. There have been no reports on the validity of the Doiguchi method, one of the popular pelvic tilt measurement methods in Japan, for approximately 30 years, necessitating an evaluation of the validity of the formula. In our study, the PT_{PS} calculated by the Doiguchi method was moderately correlated with that calculated by the DRR method, but the values were not in perfect agreement; in some cases, the PT_{PS} values were completely matched, while in others, they differed by as much as 20°, suggesting that the formula might require interindividual adjustment. The comparison of the PT_{PS} values between the Doiguchi and DRR methods using a paired *t*-test revealed that the PT_{PS} value calculated by the Doiguchi method was approximately 9° smaller than that of the DRR. It was possible that the exact intercept values could not be derived because Doiguchi's formula was based on findings from small samples. A larger intercept value of 9° in Doiguchi's formula might be more suitable; however, as shown in Figs. 2 and 3, it would be difficult to match the value of the DRR method even if it was performed. Therefore, Doiguchi's formula alone would not be able to compensate for individual differences. Since a simple linear function is not able to correct for individual differences in the values of PT_{PS}, other factors might need to be considered.

Surprisingly, the PT change from supine to lateral position calculated by the Doiguchi method was almost the same as that calculated by the DRR method; the L/T ratio is an important factor defining the change in pelvic tilt, and the slope in the linear function of the Doiguchi method was found to be almost the correct value. In fact, there were separate reports investigating changes in pelvic tilt in the supine and standing positions, with Chiba et al. using the Doiguchi method [11] and Nishihara et al. using a method such as the DRR method [12]. It was not clear whether the values obtained in their studies matched each other, but they agreed that patients with strong posterior pelvic tilt had greater backward tilt in the standing position [11,12]. Our investigation revealed that the change in pelvic tilt within an individual was related to the L/T ratio and that the slope in the linear function of the Doiguchi method was approximately the correct value. In addition, the validity of using the Doiguchi method for our cup placement procedure was also proven.

We chose the Doiguchi method over the DRR method for our cup placement procedure reported previously because 1) the Doiguchi method does not require special software. and 2) the pelvic tilt can be calculated quickly anywhere. The creation of DRR images and the adjustment of pelvic tilt on those images require special software and detailed CT image data, which are not available at all institutions. Unlike the Doiguchi method, which only requires input of measured values into the formula, the DRR method requires matching on the DRR images, which may be time-consuming to perform immediately before surgery.

In addition, although the pelvic tilt change from the supine to the lateral position was calculated in our investigation, the pelvic tilt change from the standing to the lateral position can also be calculated theoretically. In Japan, when THA is performed, the reference for cup placement is often the functional pelvic plane (FPP) in the supine position at the time of CT scanning [13]. However, for cases in which the pelvic tilt is more backward tilted in the standing position than in the supine position, surgeons may want to set the appropriate cup orientation on the X-ray images in the standing position considering the aspects of mechanical durability and dislocation resistance. In the case of our cup placement procedure, surgeons can perform cup placement based on the FPP in the standing position by simply changing the image in the supine position for measuring the L/T ratio to that in the standing position. Since this series of procedures does not necessarily require CT or special equipment, it would lead to a reduction in radiation exposure and expensive medical equipment.

There were several limitations to our study. The first was that the number of male patients was small, although the sample was statistically sufficient. The correlation of PT_{PS} between the Doiguchi method and DRR method was better in females than in males both in the supine position and in the lateral position. It is possible that the value of the intercept in Doiguchi's formula was closer to the correct value for females than for males. However, since the difference between average PT_{PS} values in the Doiguchi method and DRR method was almost the same for males and females (Table 2), we considered that the contributing factor was the small number of male cases. If the same number of males as females were available, the correlation coefficient in males might be similar to that in females. Second, since the formula by Doiguchi et al. was based on Japanese cadaveric pelvic specimens [6], it is unclear whether it can be adapted to all people in the world. In addition, the pelvic tilt measurement from anteroposterior radiographs is controversial [14]. Third, since the following factors influence the value of PT_{PS}, intra- and inter-examiner errors may be needed; however, we did not investigate this issue in this study because it was difficult to evaluate in real-world clinical practice. Four surgeons set the patient in the lateral position, including adjustment of the pelvic rotation, and held the film parallel to the direction of the trunk on the operating table [7,8]. In addition, radiology technicians were selected randomly and imaged the radiographs controlling the X-ray direction.

In conclusion, Doiguchi's pelvic tilt measurement method was verified for the first time in our study. PT_{PS} in the supine and lateral positions calculated by the Doiguchi method showed moderate correlation with those calculated by the DRR method. Pelvic tilt changes from the supine to lateral position were strongly correlated between the Doiguchi and DRR methods, and the values calculated by each method were almost identical. These results demonstrated that the L/T ratio was an important factor defining the PT change, and the formula by Doiguchi et al. was almost accurate for the slope of the linear function, although the intercept of the linear function had individual differences. Doiguchi's pelvic tilt measurement method has been partially justified, and we have also proven the validity of using Doiguchi's pelvic tilt measurement method for our cup placement procedure.

Ethics

This study was a prospective cohort study and approved by the Institutional Review Board in accordance with the Declaration of Helsinki 2013 (approval number: H30-130). The patients and/or their families were informed that data from the research would be submitted for publication, and gave their consent.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jos.2023.06.007.

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