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Original Research

Pelvic Tilt Reduces the Accuracy of Acetabular Component Placement When Using a Portable Navigation System: An In Vitro Study

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Background: A portable navigation system (PNS) was recently introduced. The PNS enables surgeons to place the acetabular component accurately. While the margin of the error for the cup abduction and anteversion was larger than the values obtained from a computed tomography-based navigation system. We hypothesized that the accuracy of the PNS might be affected by pelvic tilt.
Material and Methods: A bone substitute model of the pelvis was used in this in vitro study. We set the acetabular component using PNS. We set the acetabular component angle after changing the sagittal, coronal, and axial pelvic tilt. We calculated the difference between the angle displayed on the PNS display and the actual angle of the acetabular component. The difference in inclination angle was defined as ΔRI, and the difference in the anteversion angle was defined as ΔRA. We evaluated the trends in this ΔRI and ΔRA due to the pelvic tilt.
Results: In this in vitro study, the placement of the acetabular component was accurate in the neutral position; ΔRI was $0.5 \pm 0.7^\circ$ and ΔRA was $1.0 \pm 0.7^\circ$. Sagittal pelvic tilt and axial pelvic tilt increased both the ΔRA and ΔRI ($P = .017$). Coronal tilt increased ΔRI but did not change ΔRA.
Conclusions: While the PNS may enable surgeons to place accurate component placement in the neutral position, its accuracy decreased by pelvic tilt. The surgeons should use a solid pelvic lateral positioner for reducing discrepancies in pelvic tilt when using the PNS in the lateral decubitus position.
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Introduction

In total hip arthroplasty (THA), malalignment of the acetabular component is related to polyethylene wear, dislocation, and loosening [1-3]. Several reports have shown that a navigation system is useful when placing the acetabular component in the target position [4,5]. The rate of navigation system use in Japan, however, is only 8.75% in primary surgery and 5.8% in revision surgery because of economic reasons and prolongation of operative time [6]. To address these issues, a portable navigation system (PNS) was recently introduced. The PNS enables surgeons to place the acetabular component accurately, which reduces operative time [7].

Although good clinical and radiographical results have been reported with the use of a PNS for total knee arthroplasty [8–10], only one randomized prospective study recently reported the results of PNS use for THA. The values of deviation for cup abduction and anteversion in that study were slightly larger than the values obtained from a computed tomography (CT)-based imageless navigation system. It is not clear why the margin of error increased [11].

During the PNS registration process, the surgeon should manually set the patient's body axis parallel to the operating table. The angle definition in the PNS in the lateral decubitus position is based on the assumption that the line connecting the 2 anterior superior iliac spines is equal to the direction of gravity. However, pelvic tilt, which is one of the important factors affecting the placement of acetabular components [12,13], is not considered in this registration process in the PNS. For these reasons, pelvic tilt may affect the accuracy of the PNS for THA in the lateral decubitus position, but it is not known how pelvic tilt affects the acetabular

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component angle in the PNS. This study aimed to reveal how pelvic tilt affects the setting angle of the acetabular component in vitro.

Materials and methods

We used a bone substitute model of the pelvis that is fixed on a wooden board (Fig. 1) and a G7 acetabular cup 60 mm in diameter (Zimmer Biomet, Warsaw, IN). The model was fixed in the functional pelvic plane, and we tried to set the acetabular component to the target position, 40° of radiographic inclination (RI) and 15° of radiographic anteversion (RA), on the display of a HipAlign New Lateral PNS (OrthAlign Inc., Aliso Viejo, CA). This system consists of a display console and reference sensor. The display unit and reference sensor each have triaxial accelerometers and gyroscopes that communicate wirelessly with each other. First, the display and reference sensors were calibrated on a flat table. The metal pelvic base and navigation unit were set with 2 parallel 3.2-mm pins to the ipsilateral iliac crest. Second, the longitudinal coronal plane of the body was registered by holding the long probe parallel to the long axis of the body. The system combines them with the angle between a line drawn through both acetabular teardrops and a line from the most lateral point of the acetabular rim through the bottom of the acetabular teardrop, and the coronal registration process calculates the reference plane. During placement of the final acetabular component, a reference sensor was placed in the cup impactor, enabling display of the cup inclination and anteversion. Prior cup reaming was not performed. We set the acetabular components from the back of the pelvic model as with the posterior approach. After setting the acetabular component, we obtained CT images of these models. We used a Lightspeed VCT (GE Healthcare, Tokyo, Japan) CT system with scanning parameters of 120 kV tube voltage, 750 mA tube current, 2.5-mm slice thickness, and 2.0-mm slice interval. We measured the angle of the acetabular component using a 3D template software program (ZedHip; LEXI, Tokyo, Japan) according to a previous report [13]. We defined the true RI and RA, which are measured automatically by this software as the true acetabular angle. Two surgeons set the acetabular components 3 times, respectively, 6 times in total, for each different pelvic tilt. One surgeon is a fellow with 5 years of experience with THA, and the other surgeon has more than 10 years of experience with THA. We set sagittal tilt in this model to posterior 20°, posterior 15°, posterior 10°, posterior 5°, neutral position, anterior 5°, anterior 10°, anterior 15°, and anterior 20°. In the same way, we set and measured the acetabular component angle of coronal tilt as right tilt 20°, right tilt 15°, right tilt 10°, right tilt 5°, left tilt 5°, left tilt 10°, left tilt 15°, and left tilt 20°, and axial tilt as right rotation 20°, right rotation 15°, right rotation 10°, right rotation 5°, left rotation 5°, left rotation 10°, left rotation 15°, and left rotation 20°, respectively. The pelvic tilts were obtained by using handmade triangular wooden blocks. Figure 2 shows 20° of tilt in each direction obtained with the blocks. The difference between true RI and RI as shown on the display of the HipAlign was defined as ΔRI, and that between true RA and displayed RA was defined as ΔRA. These angles were based on Murray's definition [14]. We also defined a safe zone according to the Lewinnek definition [10], which sets 30°-50° of RI and 5°-25° of RA.

We used the Jonckheere-Terpstra test to determine whether there was a trend between the angle of the acetabular component and the pelvic tilt. A P value <.05 was considered to indicate statistical significance. All statistical analyses were performed using EZR [15].

Results

Figure 3 shows CT digital reconstruction images of an actual placement according to the display of an inclination of 40° and an anteversion angle of 15° on the PNS by changing the angle of the pelvis model. Table 1 shows the values of ΔRI and ΔRA at each position. Coronal tilt increased the difference between the angle displayed on the PNS and the actual angle, but it did not change the difference of RA.

The actual ΔRI and ΔRA values at each position for all measurements are shown on a scatter plot in Figure 4. In the neutral position and at 5° of pelvic tilt, no case deviated from the safe zone. However, at 10° of pelvic tilt, ΔRI or ΔRA was greater than 10° in 7 of the 36 cases (2 of 12 in sagittal tilt, 1 of 12 in axial tilt, and 4 of 12 in coronal tilt). At 15° of pelvic tilt, ΔRI or ΔRA was greater than 10° in 27 of the 36 cases (11 of 12 in sagittal tilt, 12 of 12 in axial tilt, and 4 of 12 in coronal tilt). Moreover, at 20° of pelvic tilt, ΔRI or ΔRA at each position was greater than 10° in all cases, and all values were outside the safe zone.

The change of cup inclination increased by 0.21°, and that of cup anteversion increased by 0.73° per one degree in the pelvic sagittal tilt. The change of cup inclination increased by 0.98°, and that of

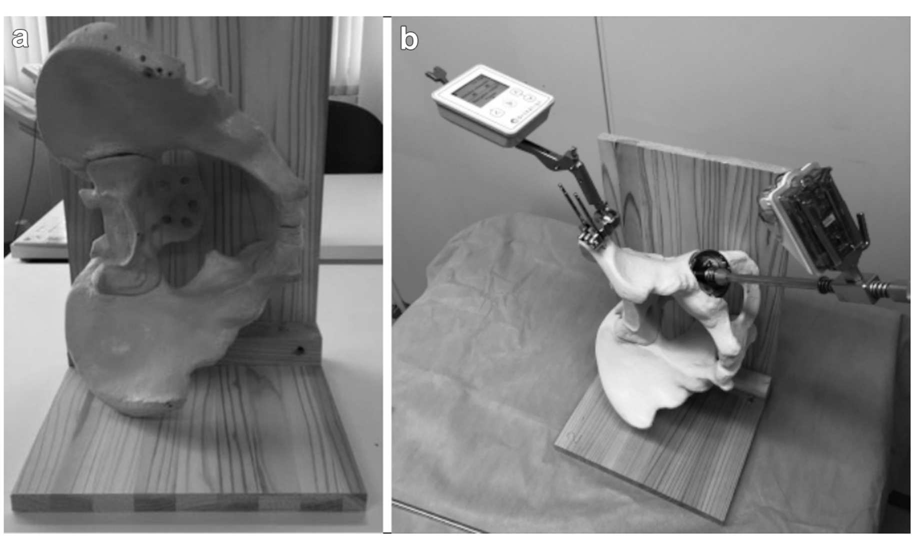

Figure 1. Bone substitute model of the pelvis, (a) which is fixed on a wooden board (left). (b) Acetabular component set up with the PNS (right).

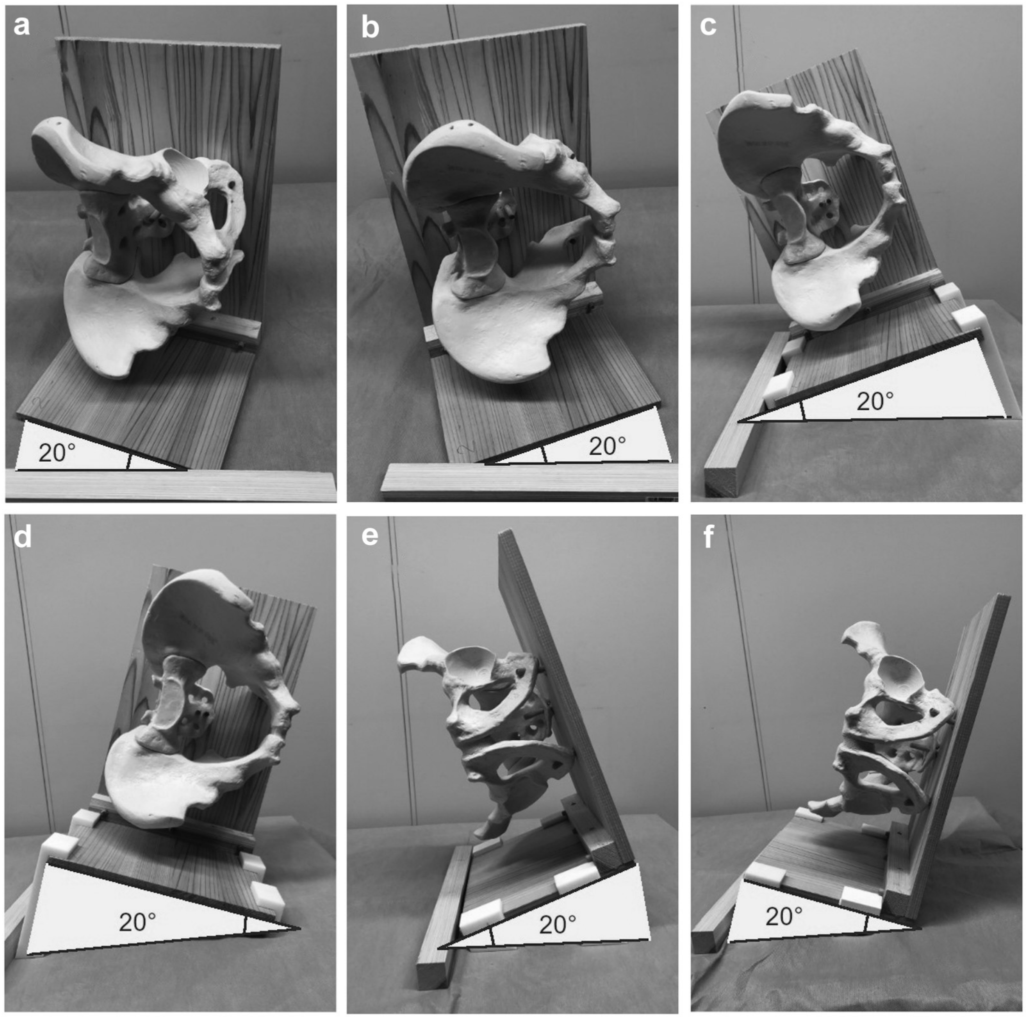

Figure 2. Pelvic model with 20° tilt. (a) Sagittal posterior tilt, (b) sagittal anterior tilt, (c) coronal right tilt, (d) coronal left tilt, (e) axial left rotation, and (f) axial right rotation.

cup anteversion did not increase or decrease in the pelvic coronal tilt. The change of cup inclination decreased by 0.28°, and that of cup anteversion increased by 0.63° per one degree in the pelvic coronal tilt.

Discussion

In this in vitro study, the placement of the acetabular component was accurate when ΔRI was 0.5 ± 0.7° and ΔRA was 1.0 ± 0.7° in the neutral position. However, we found that pelvic tilt in either direction strongly affected the acetabular component angle shown on the PNS. Even with the indicated placement by the PNS, which is 40° of RI and 15° of RA, 19% (7/36 cases) of the models with a 10° pelvic tilt in either direction and 100% (36/36 cases) of models with a 20° pelvic tilt deviated from the safe zone.

With the use of the PNS, ΔRI and ΔRA showed a certain tendency to change with sagittal tilt and axial tilt, whereas with coronal tilt, ΔRI showed a tendency to change but ΔRA did not. This result is also consistent with a previous mathematical simulation [16]. In the mathematical simulations, pelvic axial rotation, tilt, and obliquity were simulated, and the resulting changes in the intended cup position were calculated. For a cup intended to be inserted at 15° of anteversion and 40° of inclination, each degree of axial pelvic tilt induced changes of 0.64° and −0.20°, respectively. For this same cup orientation, each degree of sagittal pelvic tilt induced changes of 0.77° for anteversion and 0.17° for inclination, and for coronal pelvic tilt, each degree of obliquity induced 1° of change in inclination. Anteversion was unaffected by changes in coronal pelvic tilt. In our study, RI and RA increased by 0.37° and 0.65°, respectively, per degree increase in sagittal pelvic tilt, whereas for coronal pelvic tilt, RI changed by almost 1° per degree, but RA did not change. Another clinical study showed that functional inclination and anteversion increase by 0.29° and 0.74°, respectively, per degree increase in pelvic posterior tilt [11]. This occurs because the PNS is based on accelerometry, and inclination is defined by the direction of gravity, whereas the body axis, on which anteversion is based, is determined by table registration. In other words, sagittal pelvic tilt causes an increase of operative anteversion, which leads to an increase of both true RI and true RA. In contrast, coronal tilt causes an increase of true RI but does not affect true RA. Axial pelvis tilt causes an increase of anatomical anteversion that leads to a decrease of true RI and an increase of true RA. When combined the posterior sagittal tilt and right axial rotation, the difference of the cup anteversion became much greater. If the patient had a posterior pelvic tilt due to the spinal deformity and set in the rotational position, the cup anteversion becomes much smaller. It would become a risk of the dislocation.

As shown in Figure 4 from the viewpoint of the safe zone, although the tendency varies depending on the direction of tilt, a 10° pelvic tilt can lead to deviation from the safe zone. A pelvic tilt

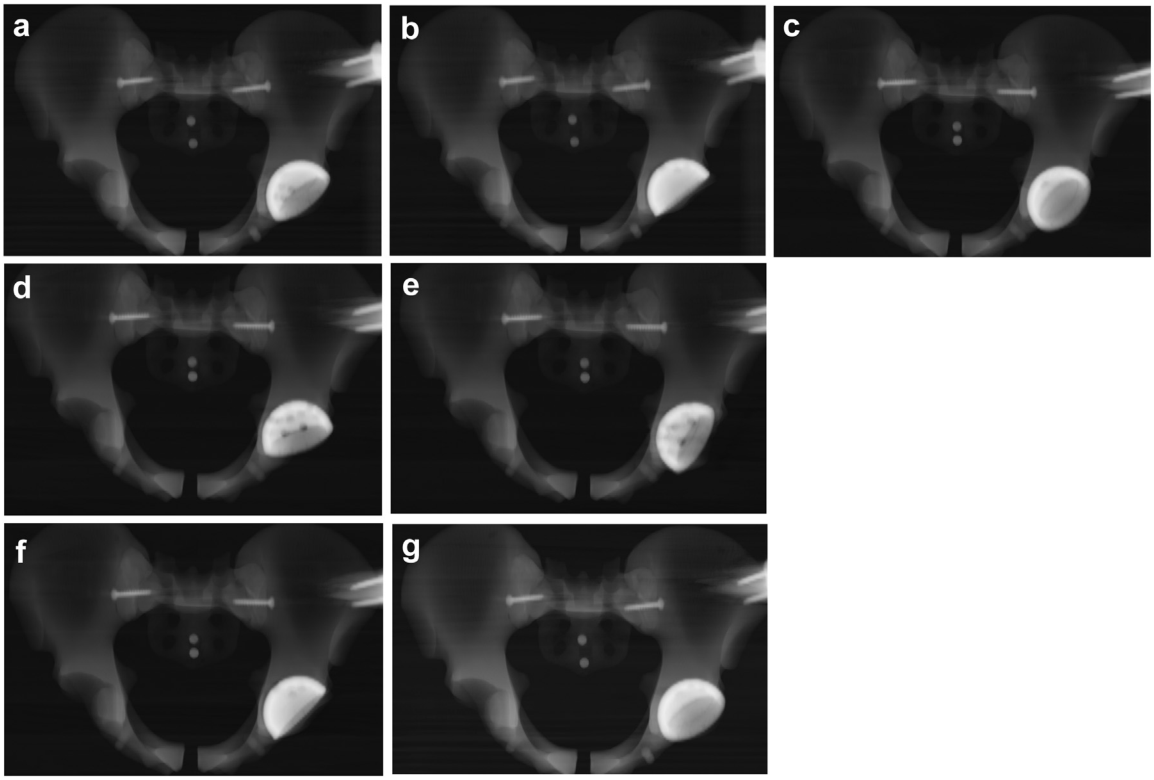

Figure 3. Digital reconstruction radiographs. (a) Neutral, (b) 20° sagittal posterior tilt, (c) 20° sagittal anterior tilt, (d) 20° coronal right tilt, (e) 20° coronal left tilt, (f) 20° axial right rotation, and (g) 20° axial left rotation.

of 20° or more makes it almost impossible for a surgeon to set an acetabular component in the safe zone, although this is very unlikely in the clinical setting. Tanino et al. [12] reported that this is why a PNS was less accurate than a CT-based navigation system. The pelvic position is more reliable when the patient is in the supine position, leading to more consistent orientation of the acetabular component. Significant differences in pelvic tilt and rotation are seen with the patient in the lateral decubitus position [17]. The PNS could provide the good accuracy of cup orientation during THA in the supine position [7]. It suggested that the position capture system of the PNS is reliable at the start of the surgery. The pelvic movement during the operation in the sagittal plane was from 11° to 20°, from 7° to 14° in the axial plane, and from 9° to 12° in the coronal plane in the lateral decubitus position [13]. Therefore, the pelvic movement in the lateral decubitus position would affect the accuracy of the PNS in our study. Some reports note that the use of an anatomical-pelvic plane positioner [18] and fluoroscopic imaging is effective in preventing pelvic tilt during the surgery [14]. The angle of PNS may be more accurate in the decubitus position by using these methods.

There are limitations in our study. First, we did not assess factors that affect the placement of the acetabular component, for example, soft tissue, because we used a pelvic model. Second, the impaction energy required to fit the acetabular component could deform the pelvic model and wooden board, which may have resulted in the variations. Third, we only assessed a single direction of pelvic tilt and did not assess the combination of axial, sagittal, and coronal pelvic tilt that can occur intraoperatively. Fourth, we set the acetabular component in the left acetabulum only. This might have affected the results because both operators were right-handed. However, the result would be reversed regarding left and right tilt and rotation if we set it in the right acetabulum. Finally, we only assessed combinations with the pelvis, and any correlation with spinal alignment is unknown.

Table 1
Changes in ΔRI and ΔRA in accordance with pelvic tilt (n = 6).

Sagittal tilt	Posterior tilt 20°	Posterior tilt 15°	Posterior tilt 10°	Posterior tilt 5°	Neutral	Anterior tilt 5°	Anterior tilt 10°	Anterior tilt 15°	Anterior tilt 20°	*P* value
ΔRI (degrees)	−0.95 ± 0.4	−2.4 ± 0.2	−0.4 ± 0.7	−1.4 ± 0.1	0.5 ± 0.7	1.4 ± 0.2	3.7 ± 0.8	5.0 ± 0.6	7.9 ± 0.7	< .001
ΔRA (degrees)	−15.2 ± 0.4	−11.6 ± 0.2	−7.2 ± 0.6	−3.7 ± 0.2	1.0 ± 0.7	3.2 ± 0.3	9.0 ± 0.6	10.3 ± 0.3	13.9 ± 0.4	< .001
Coronal tilt	Right tilt 20°	Right tilt 15°	Right tilt 10°	Right tilt 5°	Neutral	Left tilt 5°	Left tilt 10°	Left tilt 15°	Left tilt 20°	
ΔRI (degrees)	−19.2 ± 0.3	−14.5 ± 0.3	−9.9 ± 0.5	−4.6 ± 0.4	0.5 ± 0.7	5.3 ± 0.2	10.5 ± 0.2	15.3 ± 0.2	20.0 ± 0.4	< .001
ΔRA (degrees)	0.9 ± 0.3	−0.3 ± 0.2	1.4 ± 0.4	0.1 ± 0.1	1 ± 0.7	−0.4 ± 0.2	1.4 ± 0.5	−0.3 ± 0.2	−0.1 ± 0.4	.214
Axial tilt	Right rotation 20°	Right rotation 15°	Right rotation 10°	Right rotation 5°	Neutral	Left rotation 5°	Left rotation 10°	Left rotation 15°	Left rotation 20°	
ΔRI (degrees)	4.3 ± 0.5	2.8 ± 0.2	3.4 ± 0.2	1.2 ± 0.2	0.5 ± 0.7	−1.3 ± 0.3	−2.0 ± 0.4	−5.4 ± 0.2	−6.8 ± 0.3	< .001
ΔRA (degrees)	−13.4 ± 0.3	−10.2 ± 0.3	−6.6 ± 0.5	−3.1 ± 0.3	1 ± 0.7	3.3 ± 0.3	6.9 ± 0.3	9.2 ± 0.3	11.4 ± 0.3	< .001

RA, radiographic anteversion; RI, radiographic inclination.

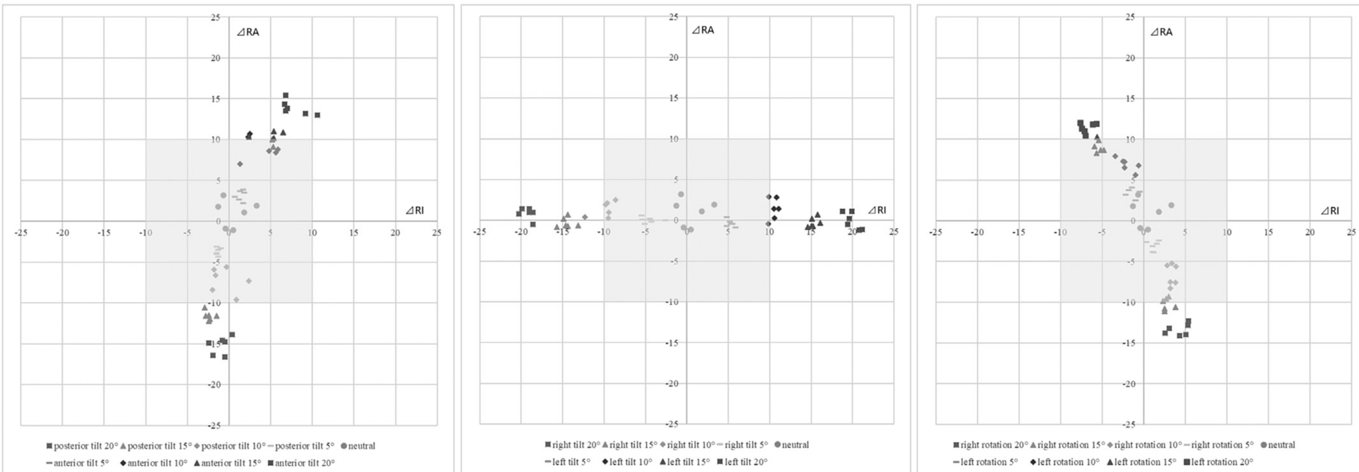

Figure 4. Boxplots of ΔRA and ΔRI. Each plot shows the actual acetabular component. The center of the light gray square indicates the safe zone.

Conclusions

While the PNS may enable surgeons to place accurate component placement in the neutral position, its accuracy decreased by pelvic tilt. The surgeons should use a solid pelvic lateral positioner for reducing discrepancies in pelvic tilt when using the PNS in the lateral decubitus position.

Conflict of interests

The authors declare there are no conflicts of interest.

References

[1] Patil S, Bergula A, Chen PC, Colwell Jr CW, D'Lima DD. Polyethylene wear and acetabular component orientation. J Bone Joint Surg Am 2003;85-A(Suppl 4):56.
[2] Nishii T, Sugano N, Miki H, Koyama T, Takao M, Yoshikawa H. Influence of component positions on dislocation: computed tomographic evaluations in a consecutive series of total hip arthroplasty. J Arthroplasty 2004;19(2):162.
[3] Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 2005;87(6):762.
[4] Iwana D, Nakamura N, Miki H, Kitada M, Hananouchi T, Sugano N. Accuracy of angle and position of the cup using computed tomography-based navigation systems in total hip arthroplasty. Comput Aided Surg 2013;18(5-6):187.
[5] Xu K, Li YM, Zhang HF, et al. Computer navigation in total hip arthroplasty: a meta-analysis of randomized controlled trials. Int J Surg 2014;12(5):528.
[6] THA Registry. Japanese society for replacement arthroplasty. Tokyo: JSRA; 2018. https://jsra.info/pdf/THA20180331.pdf.
[7] Kamenaga T, Hayashi S, Hashimoto S, et al. Accuracy of cup orientation and learning curve of the accelerometer-based portable navigation system for total hip arthroplasty in the supine position. J Orthop Surg 2019;27(2):1.
[8] Blendea S, Eckman K, Jaramaz B, Levison TJ, Digioia 3rd AM. Measurements of acetabular cup position and pelvic spatia orientation after total hip arthroplasty using computed tomography radiography matching. Comput Aided Surg 2005;10:37.
[9] Murray DW. The definition and measurement of acetabular orientation. J Bone Joint Surg 1993;75-B:228.
[10] Lewinnek GE, Lexis JL, Tarr R, Compere CL, Zimmerman JR. Dislocation after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60(2):217.
[11] Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ. Pelvic tilt in patients undergoing total hip arthroplasty: when does it matter? J Arthroplasty 2015;30(3):387.
[12] Tanino H, Nishida Y, Mitsutake R, Ito H. Portable accelerometer-based navigation system for cup placement of total hip arthroplasty: a prospective, randomized, controlled study. J Arthroplasty 2019;35(1):172.
[13] Kanazawa M, Nakashima Y, Ohishi M, et al. Pelvic tilt and movement during total hip arthroplasty in the lateral decubitus position. Mod Reumatol 2016;26(3):435.
[14] Nishikubo Y, Fujioka M, Ueshima K, Saito M, Kubo T. Preoperative fluoroscopic imaging reduces variability of acetabular component positioning. J Arthroplasty 2011;26(7):1088.
[15] Kanda Y. Investigation of the freely available easy-to-use software "EZR" for medical statistics. Bone Marrow Transpl 2013;48(3):452.
[16] Vigdorchik JM, Muir JM, Buckland A, et al. Undetected intraoperative pelvic movement can lead to Inaccurate acetabular cup component placement during total hip arthroplasty: a mathematical simulation Estimating change in cup position. J Hip Surg 2017;01(04):186.
[17] Grammatopoulos G, Gofton W, Cochran M, et al. Pelvic positioning in the supine position leads to more consistent orientation of the acetabular component after total hip arthroplasty. Bone Joint J 2018;100-B(10):1280.
[18] Iwakiri K, Kobayashi A, Ohta Y, Takaoka K. Efficacy of the anatomical-pelvic-plane positioner in total hip arthroplasty in the lateral decubitus position. J Arthroplasty 2017;32(5):1520.