New cross-table lateral radiography method for measuring acetabular component anteversion in total hip arthroplasty

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Abstract

Introduction

Various methods have been described for measuring acetabular component anteversion. However, accurate measurement of anteversion is difficult. We herein propose a new method using cross-table lateral (CL) radiography performed with the contralateral hip flexed to 45° (45° flexed CL radiography). The main purpose of this study was to evaluate the reliability and validity of this new method.

Methods

The study group included 93 patients who underwent total hip arthroplasty (THA). All hips were evaluated with computed tomography (CT) and both standard and 45° flexed CL radiographs to measure acetabular component anteversion next week after THA. The intraobserver and interobserver reliability of each measurement was assessed. Plain radiography measurements were compared with the reference CT measurements to evaluate their validity.

Results

All measurements had excellent intraobserver and interobserver reliability, and plain radiography measurements correlated well with CT measurements. The mean measurements were 21.9° (3°–39°) with CT, 24.9° (7°–47°; $p < 0.001$) with standard CL radiographs, and 22.5° (7°–43°; $p = 0.112$) with 45° flexed CL radiographs.

Discussion

The anteversion values measured with our new method were closer to the CT values used as a reference standard than those with standard CL radiographs. Our new method appears to be reliable and valid for measuring acetabular component anteversion.

Key words: acetabular component anteversion, total hip arthroplasty, cross-table lateral radiography

INTRODUCTION

The orientation of the acetabular component has been shown to be important for improving function and preventing failure after total hip arthroplasty (THA) (1-4). Acetabular component orientation is described by inclination and version angles. The inclination can be measured on anteroposterior (AP) radiographs, while anteversion can be measured on AP radiographs or cross-table lateral (CL) radiographs. Anteversion is more difficult to measure accurately despite the use of several methods of measuring the version angle on AP radiographs or CL radiographs (3-8).

CL radiographs are widely used to assess acetabular component anteversion as part of routine evaluation after THA because the measurement on CL radiographs can be obtained directly from the image without complicated calculations. However, some publications have questioned the accuracy of the measurement on CL radiographs (9, 10). For standard CL radiography, patients are placed in the supine position with the contralateral hip flexed to 90° (4). Previous studies have discussed that inaccurate measurement on CL radiographs might been attributed to variations in pelvic tilt and rotation because of this flexion of the contralateral hip, especially for the patients with contralateral hip stiffness (11, 12). Therefore, we devised a new CL radiography method with which to measure acetabular component anteversion.

With our new method, namely 45° flexed CL radiography, the contralateral hip is flexed to 45° during CL radiography. The purposes of this study were to evaluate (1) the reliability and validity of this new method for measuring acetabular component anteversion and (2) the influence of contralateral hip stiffness on the measurements obtained with our new method and standard CL radiographs.

PATIENTS AND METHODS

This prospective study was approved by our institutional review board, and informed consent was obtained from all of the patients. Patients undergoing primary THA from April 2013 to June 2014 were eligible for inclusion in this study. In total, 93 consecutive patients who underwent primary THA were evaluated. The exclusion criteria were the presence of Crowe type III to IV dysplasia or the performance of revision hip surgery to minimize the effect of pelvic deformity on the measurements. The patients comprised 17 men and 76 women with a mean age of 61.6 years (range, 20–89 years). They had a mean body mass index (BMI) of 23.3 kg/m^2 (range, 16.3–39.6 kg/m^2) at the time of the operation. The indications for THA were osteoarthritis in 78 hips (83.9%), osteonecrosis in 13 hips (14.0%), and rapidly destructive coxarthropathy in 2 hips (2.2%).

To enable determination of the influence of contralateral hip stiffness on the measurements, the preoperative maximum flexion angle of the contralateral hip joint was categorized as ≥90° or <90°. The ≥90° group was defined as the "contralateral non-stiff" group, and the <90° group was defined as the "contralateral stiff" group. The contralateral non-stiff group comprised 74 patients (59 women, 15 men) with a mean age of 61.0 years (range, 20–80 years), and the contralateral stiff group comprised 19 patients (17 women, 2 men) with a mean age of 63.9 years (range, 41–89 years). In the contralateral stiff group, 17 patients had bilateral osteoarthritis and 2 patients had undergone THA on the contralateral hip. We compared the following demographic data between the two groups: age, sex, BMI, preoperative maximum flexion angle of the contralateral hip, and the approach used in the procedures (Table I).

Three experienced orthopedic surgeons performed all operations using a posterolateral approach or a direct anterior approach. Cementless THA without a navigation system was performed in all cases. The orientation of the acetabular component was assessed using an alignment guide, which provided estimates of inclination and anteversion. The target operative angles were 40° (inclination) and 20° (anteversion).

Image acquisition

Plain radiographs including standard CL, 45° flexed CL and AP pelvis radiographs were obtained next week after THA and used to measure anteversion of the acetabular component. Standard CL radiographs were obtained with the contralateral hip flexed to 90° (Fig. 1A). The direction of the X-ray beam was parallel to the examination table and 45° cranial to the long axis of the trunk. The film was seated perpendicular to the examination table using a film holder. Similarly, 45° flexed CL radiographs were obtained with the contralateral hip flexed to 45° using an angle-measuring instrument (Fig. 1B).

All pelvic computed tomography (CT) scans were performed next week after THA. All patients were placed in the supine position with the hip in a neutral position during the CT scans. We used a 64-channel multidetector CT system (Aquilion TSX-101A/HA; Toshiba Medical Systems, Tokyo, Japan), and the scan protocol had a slice distance of 0.5 mm from the anterior-superior iliac spines to below the knee. All images were digitally acquired using the Picture Archiving and Communication System (PACS).

Measurement of acetabular component version

Version angles on standard CL radiographs (VCL) and 45° flexed CL radiographs (45° VCL) were measured between the vertical line of the film and the tangent line of the opening face of the acetabular component (Fig. 2A, B). Version angles on AP pelvis radiographs (VAP) were measured by the method of Widmer (8). On CT scans, inclination and anteversion were measured with a supine functional pelvic plane (FPP) as the reference. First, a sagittal multiplanar reconstruction plane that was perpendicular to the line passing through the bilateral anterosuperior iliac spine was reconstructed. Second, the anteversion, defined as the angle between a line perpendicular to the FPP and the opening face of the acetabular component, was measured on the sagittal plane. This angle was termed the operative anteversion. Third, the pelvis was tilted frontward on the computer image with the measured operative anteversion. The inclination between the opening face of the acetabular component and an inter-teardrop line was measured on the coronal multiplanar reconstruction plane. This angle was the operative inclination. Finally, the operative inclination and anteversion were converted into radiographic angles using the formula described by Murray (13). This radiographic anteversion (i.e., the version angle on CT [VCT]) was used for analysis.

The acetabular component anteversion was measured on the plain radiographs (standard, 45° flexed CL and AP pelvis radiographs) and CT scans by three independent examiners on three separate occasions. All measurements were made without knowledge of the clinical information or the findings of the other examiners. The mean value of the three measurements made by each examiner was regarded as the anteversion. The VCT was regarded as the reference standard.

Assessment of reliability and convergent validity

Intraobserver reliability was evaluated by testing one examiner on three occasions using plain radiographs and CT scans. Interobserver reliability was evaluated across the three examiners. Convergent validity was defined as the proximity of the VCL, 45° VCL and VAP measurements to the VCT reference standard. Correlations between measurements taken from the plain radiographs and CT scans were then analyzed.

Statistical analysis

The Mann–Whitney test was used to compare the demographic data between the two groups. The chi-squared test was used to compare categorical and binary variables, such as sex and the approach used in the procedures, between the two groups. The intraclass correlation coefficient (ICC) and 95% confidence interval were used to summarize interobserver reliability. Intraobserver and interobserver reliabilities were evaluated using a two-way random model assuming a single measurement and absolute agreement. An ICC of 1 indicated perfect reliability, while an ICC of 0 indicated the opposite. The paired t-test and Pearson's correlation coefficients were used to determine the convergent validity of the anteversion measured on each plain radiograph with the corresponding CT scan. Statistical analyses were performed using SPSS version 20 software (SPSS, Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

RESULTS

All intraobserver and interobserver ICCs were excellent for the measurements taken from plain radiographs and CT scans (Table II). The measurements from both standard and 45° flexed CL radiographs showed good positive correlations with the CT measurements (Fig. 3). The mean measurements were 21.9° (3°–39°) with CT, 24.9° (7°–47°; $p < 0.001$) with standard CL radiographs, 22.5° (7°–43°; $p = 0.112$) with 45° flexed CL radiographs, and 23.8° (3°–56°; $p = 0.006$) with AP pelvis radiographs (Table III). The anteversion values measured with our new 45° CL method were close to the CT values, whereas the measurements with standard CL and AP pelvis radiographs differed significantly from the CT measurements.

In the contralateral non-stiff group, the mean VCT, VCL, and 45° VCL were 22.1° (6°–39°), 24.7° (7°–47°; $p < 0.001$), and 22.6° (7°–43°; $p = 0.151$), respectively (Table III). In the contralateral stiff group, the mean VCT, VCL, and 45° VCL were 21.3° (3°–29°), 25.8° (11°–37°; $p < 0.001$), and 21.7° (8°–34°; $p = 0.513$), respectively. The 45° VCL values were similar to the VCT values in both groups, whereas the VCL values were significantly different from the VCT values, especially in the contralateral stiff group.

DISCUSSION

The orientation of the acetabular component is crucial for movement, stability, and wear reduction (1-4). Lewinnek et al. (3) recommended an inclination of 40° ± 10° and an anteversion of 15° ± 10° as the safe zone for acetabular component orientation. Various radiological methods have been developed to measure anteversion of the acetabular component (3-8). However, it is difficult to measure the anteversion accurately. Previous studies have shown that CT provides accurate measurement of the acetabular component orientation after THA (14-16), but CT is expensive and involves a considerable amount of radiation exposure. Plain radiography is the most important imaging modality for postoperative evaluation in clinical practice because it entails lower radiation exposure and has a lower cost than CT. Therefore, we devised a new CL radiography method performed with the contralateral hip flexed to 45° for measuring acetabular component anteversion.

When assessing the accuracy of radiological measurements, intraobserver and interobserver reliabilities should be evaluated. A high ICC for anteversion measurements taken from CL radiographs has been reported (9, 12, 17). We also found high intraobserver and interobserver reliabilities in this study. Our new method had almost the same reliability as standard CL radiography.

To ensure validity of radiographic methods used to measure acetabular component orientation, it is most important to use the same definition and reference pelvic plane among individual methods. It is possible to measure acetabular component anteversion with the use of three different definitions: radiographic, anatomical, and operative (13). Because these definitions have different values, it is inappropriate to compare them directly. Although measurements on CL radiographs were based on the supine FPP, both the anterior pelvic plane (APP) and the FPP have been used as reference pelvic planes on CT. However, these two planes are not always an approximation because of individual pelvic tilt in the supine position. Babisch et al. (18) reported that the APP varies individually, and is not neutral when the patient is in the supine position. Miki et al. (19) recommended using the FPP on CT as a reference plane for acetabular component orientation planning. Therefore, whenever acetabular component orientation is discussed, it is essential to compare the measurement values using the same definition and reference plane. However, previous studies on the accuracy of measuring the acetabular component orientation have confused these factors (17, 20, 21). In this study, we used the radiographic definition and the supine FPP as the reference plane on CT. We therefore believe that we could appropriately compare the measurements on plain radiographs with those on CT for validity. The anteversion values with our new method showed a good positive correlation with the CT values and were close to the reference CT values. In contrast, the anteversion values obtained with standard CL or AP radiographs were significantly different from the CT values. The present study showed that our new method had good reliability and validity for measuring acetabular component anteversion.

CL radiographs have been used to measure acetabular component anteversion for convenience and simplicity. However, some studies have revealed the inaccuracy of the VCL (9, 10). Using the VCT for comparison, Nishino et al. (12) reported that the mean measurement difference was 2.80° ± 4.10° for the VCL and −0.57° ± 3.10° for the VAP. These authors suggested that the mean difference for the VAP was significantly smaller than the mean difference for the VCL and, accordingly, recommended that measurements of the version angle be made on AP radiographs rather than CL radiographs. However, only a few reports have determined the influences of contralateral hip stiffness on the measurement of acetabular component anteversion on CL radiographs. Arai et al. (11) reported that the poor-range (maximum flexion angle of the contralateral hip joint) group had a significantly larger version difference (VCL – VAP) than the good-range group (6.4° ± 4.1° versus 3.5° ± 3.7°, respectively). Our results also showed that the VCL values were significantly different from the VCT values, especially in the patients with contralateral hip stiffness. The mean difference (VCL – VCT) in the patients with contralateral hip stiffness tended to be larger than that in the patients without contralateral hip stiffness. In contrast, there was little difference between the 45° VCL and VCT values in the patients with or without contralateral hip stiffness, indicating that measurements on 45° flexed CL radiographs were not influenced by contralateral hip stiffness.

AP radiographs have also been used for measurement of acetabular component anteversion. However, this use of AP radiographs also has some disadvantages. It is difficult to identify the apex of the ellipse on AP radiographs, depending on the articulation type or the extent of the anteversion (5). Although a previous radiographic study used template software that could automatically identify an ellipse of the acetabular component (12), the software is not widely used in clinical practice. In the present study, the VAP values ranged widely and were significantly different to the VCT values. If we had used the template software, we might have been able to more accurately measure anteversion on AP radiographs. Furthermore, CL radiographs are required to detect retroversion, which cannot be detected on AP radiographs (22). There were no hips with retroversion according to CT measurements in the present study.

Our study had several limitations. First, the gold standard for validation of radiological measurements in vivo has not been established. Because several studies have shown that the acetabular component orientation can be accurately measured using CT images (14-16), we defined CT measurements as our reference standard. Second, we did not study the impact of pelvic mobility. There might be a difference in the values measured with a hypermobile versus a stiff pelvis. However, most arthritic patients have a stiff pelvis rather than a hypermobile pelvis; thus, pelvic mobility is unlikely to have influenced the measurements in this study. Finally, with our new method of 45° flexed CL radiographs, the acetabular component shape might be indistinct because of overlap of the contralateral thigh. However, there were no patients whose femur overlapped with the acetabular component in this study. We were able to measure the anteversion of all patients after digitally adjusting the radiographic contrast on PACS because the acetabular component is less radiolucent than soft tissue.

CONCLUSION

Our new method of 45° flexed CL radiography is easily performed and involves less radiation exposure than CT scans. The anteversion values obtained with our new method were closer to the CT values used as a reference standard than the values obtained with standard CL or AP radiographs. Our results indicate that the measurements on 45° flexed CL radiographs may not be influenced by contralateral hip stiffness. Our new method appears to be reliable and valid for measuring acetabular component anteversion after THA for patients with or without contralateral hip stiffness.

Financial support: No financial support was received for this study.

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

References

1. Barrack RL. Dislocation after total hip arthroplasty: implant design and orientation. J Am Acad Orthop Surg 2003;11(2):89-99.
2. Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty 1998;13(5):530–534.
3. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60(2):217–220.
4. Woo RY, Morrey BF. Dislocations after total hip arthroplasty. J Bone Joint Surg Am 1982;64(9):1295–1306.
5. Hassan DM, Johnston GH, Dust WN, Watson LG, Cassidy D. Radiographic calculation of anteversion in acetabular prostheses. J Arthroplasty 1995;10(3):369–372.
6. Liaw CK, Hou SM, Yang RS, Wu TY, Fuh CS. A new tool for measuring cup orientation in total hip arthroplasties from plain radiographs. Clin Orthop 2006;451:134–139.
7. Pradhan R. Planar anteversion of the acetabular cup as determined from plain anteroposterior radiographs. J Bone Joint Surg Br 1999;81(3):431–435.
8. Widmer KH. A simplified method to determine acetabular cup anteversion from plain radiographs. J Arthroplasty 2004;19(3):387–390.

9. Ghelman B, Kepler CK, Lyman S, Della Valle AG. CT outperforms radiography for determination of acetabular cup version after THA. Clin Orthop Relat Res 2009;467(9):2362–2370.
10. Nunley RM, Keeney JA, Zhu J, Clohisy JC, Barrack RL. The reliability and variation of acetabular component anteversion measurements from cross-table lateral radiographs. J Arthroplasty 2011;26(6):84–87.
11. Arai N, Nakamura S, Matsushita T. Difference between 2 measurement methods of version angles of the acetabular component. J Arthroplasty 2007;22(5):715–720.
12. Nishino H, Nakamura S, Arai N, Matsushita T. Accuracy and precision of version angle measurements of the acetabular component after total hip arthroplasty. J Arthroplasty 2013;28(9):1644–1647.
13. Murray DW. The definition and measurement of acetabular orientation. J Bone Joint Surg Br 1993;75(2):228–232.
14. Kalteis T, Handel M, Herold T, Perlick L, Paetzel C, Grifka J. Position of the acetabular cup: accuracy of radiographic calculation compared to CT-based measurement. Eur J Radiol 2006;58(2):294–300.
15. Olivecrona H, Weidenhielm L, Olivecrona L, Beckman MO, Stark A, Noz ME, Maguire GQ Jr, Zeleznik MP, Svensson L, Jonson T. A new CT method for measuring cup orientation after total hip arthroplasty: a study of 10 patients. Acta Orthop Scand 2004;75(3):252–260.
16. Wines AP, McNicol D. Computed tomography measurement of the accuracy of component version in total hip arthroplasty. J Arthroplasty 2006;21(5):696–701.

17. McArthur B, Cross M, Geatrakas C, Mayman D, Ghelman B. Measuring acetabular component version after THA: CT or plain radiograph? Clin Orthop Relat Res 2012;470(10):2810–2818.
18. Babisch JW, Layher F, Amiot LP. The rationale for tilt-adjusted acetabular cup navigation. J Bone Joint Surg Am 2008;90(2):357–365.
19. Miki H, Kyo T, Sugano N. Anatomical hip range of motion after implantation during total hip arthroplasty with a large change in pelvic inclination. J Arthroplasty 2012;27(9):1641–1650.
20. Marx A, von Knoch M, Pförtner J, Wiese M, Saxler G. Misinterpretation of cup anteversion in total hip arthroplasty using planar radiography. Arch Orthop Trauma Surg 2006;126(7):487–492.
21. Nho JH, Lee YK, Kim HJ, Ha YC, Suh YS, Koo KH. Reliability and validity of measuring version of the acetabular component. J Bone Joint Surg Br 2012;94(1):32–36.
22. Ackland MK, Bourne WB, Uhthoff HK. Anteversion of the acetabular cup. Measurement of angle after total hip replacement. J Bone Joint Surg Br 1986;68(3):409–413.

Table I - Patient demographics for the contralateral non-stiff and stiff groups

Characteristic	Mean (range)		p-value
	Non-stiff group (n = 74)	Stiff group (n = 19)	
Age (years)	61.0 (20–80)	63.9 (41–89)	0.332
Sex (male:female)	15:59	2:17	0.319
Body mass index (kg/m^2)	22.9 (16.3–30.0)	24.9 (16.8–39.6)	0.099
Maximum flexion angle (º)	115.1 (90–140)	76.8 (70–80)	<0.001
Approach (no.)			
Posterolateral	31	12	0.099
Direct anterior	43	7	

Table II - Intraobserver and interobserver reliabilities of each measurement

Method	Intraobserver reliability（ICC, 95%CI）	Interobserver reliability（ICC, 95%CI）
CT scan	0.986 (0.980–0.990)	0.983 (0.973–0.990)
Standard CL radiographs	0.970 (0.957–0.979)	0.991 (0.986–0.995)
45° Flexed CL radiographs	0.968 (0.955–0.978)	0.987 (0.980–0.992)
AP radiographs	0.962 (0.943–0.975)	0.896 (0.798–0.951)

ICC: intraclass correlation coefficient; CI: confidence interval;

CT: computed tomography; CL: cross-table lateral; AP: anteroposterior

Table III - Validity of version angle measured by each method

Method, by group (contralateral)	Mean (range)(°)	p-value	Mean difference compared with CT (°)
Total (n = 93)			
VCT	21.9 (3–39)	Reference	Reference
VCL	24.9 (7–47)	<0.001	3.0 (-4 to 13)
45° VCL	22.5 (7–43)	0.112	0.5 (-7 to 13)
VAP	23.8 (3–56)	0.006	2.8 (-11 to 21)
Non-stiff group (n = 74)			
VCT	22.1 (6–39)	Reference	Reference
VCL	24.7 (7–47)	<0.001	2.6 (-4 to 13)
45° VCL	22.6 (7–43)	0.151	0.6 (-7 to 13)
VAP	24.0 (3–56)	0.019	2.7 (-11 to 21)
Stiff group (n = 19)			
VCT	21.3 (3–29)	Reference	Reference
VCL	25.8 (11–37)	<0.001	4.6 (-4 to 13)
45° VCL	21.7 (8–34)	0.513	0.5 (-5 to 6)
VAP	23.1 (7–50)	0.162	3.0 (-7 to 21)

VCT: version angle measured by CT

VCL: version angle measured by standard cross-table lateral radiographs

45° VCL: version angle measured by 45° flexed cross-table lateral radiographs

VAP: version angle measured by anteroposterior radiographs

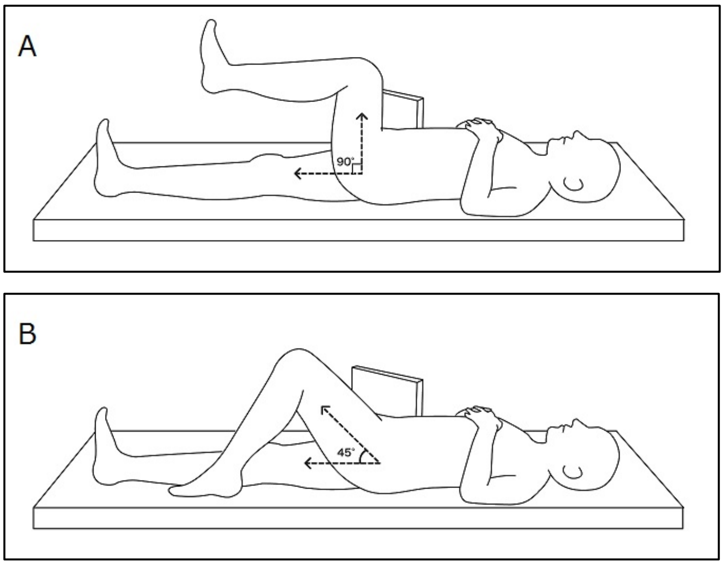

Fig. 1 - A) Standard CL radiographs were obtained with the contralateral hip flexed to 90°. **B)** Our 45° flexed CL radiographs were obtained with the contralateral hip flexed to 45° using an angle-measuring instrument.

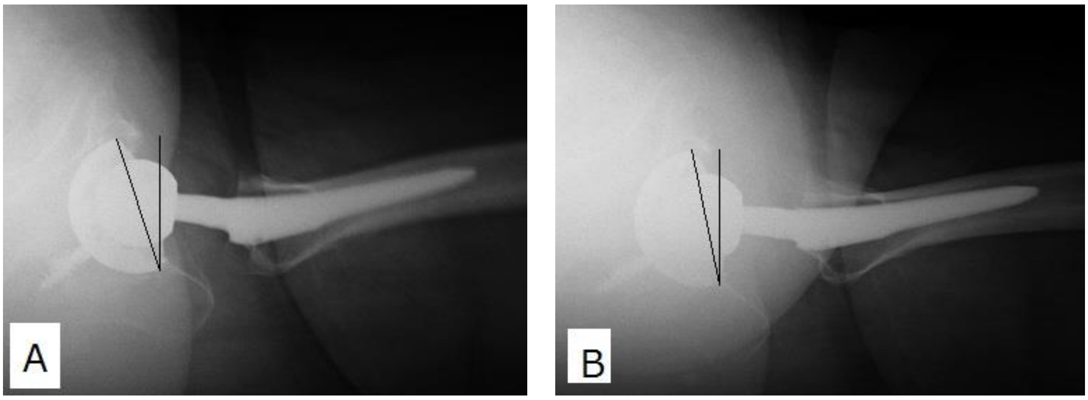

Fig. 2 - Measurement of anteversion in the same patient. **A)** Anteversion on standard CL radiographs was 18.5°. **B)** Anteversion on 45° flexed CL radiographs was 11.8°.

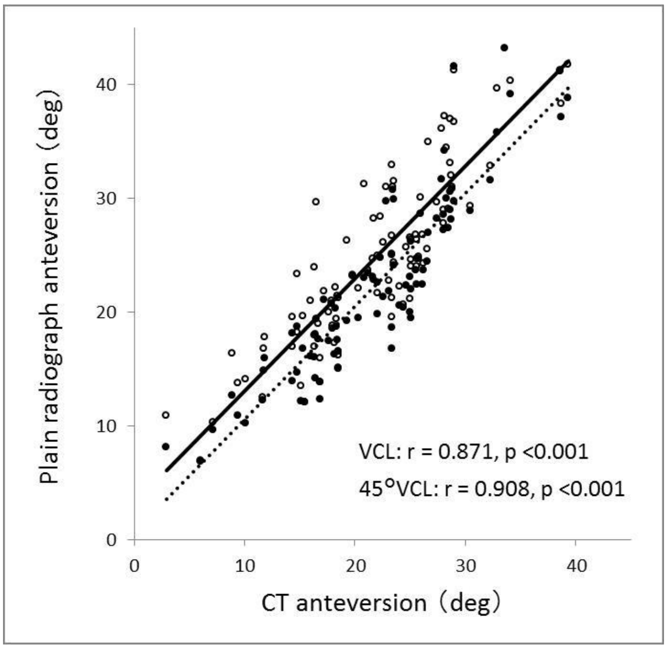

Fig. 3 - Scatter plots of version measured on cross-table lateral radiographs (VCL) and 45° flexed cross-table lateral radiographs (45° VCL) versus computed tomography-derived anteversion data. *Open circles*: VCL; *filled circles*: 45° VCL; *solid lines*: VCL approximate line; *dotted lines*: 45° VCL approximate line.