Malposition of the acetabular component after total hip arthroplasty (THA) is associated with dislocation, limited range of movement and increased polyethylene wear. Anteversion has been defined differently in various circumstances. Murray has described these as anatomical, operative and radiographic anteversion. Anatomical anteversion is the angle between the acetabular axis and the transverse axis of the trunk; operative anteversion is the angle between the longitudinal axis of the trunk and the acetabular axis when projected onto the sagittal plane; and radiographic anteversion is the angle between the acetabular axis and the coronal plane. The position of the acetabular component can be measured from either plain radiographs or computed tomography (CT). Although CT is more accurate and involves measurements which are independent of the patient’s position, there are differences in that anteversion measured on CT scans actually reflects anatomical anteversion whereas plain radiographs present radiographic anteversion. In addition, because of their easy accessibility, plain radiographs continue to be accepted as the primary imaging method for evaluation after THA.

Although the inclination of the acetabular component can be measured from plain radiographs easily, the calculation of anteversion still presents problems. Various methods have been established to evaluate anteversion of the acetabular component from plain radiographs, but no standardised method has been established.

The most widely used and easy method for measuring anteversion of the acetabular component with plain radiographs is the method of Woo and Morrey. This method uses cross-table lateral radiographs and allows anteversion and retroversion to be distinguished. The circular opening of the component is projected as an ellipse in an anteroposterior (AP) radiograph. Measurements of anteversion from these elliptical projections have been adopted in various other methods of measurement. The method of Liaw et al is one such technique and is considered to be relatively accurate. Other methods using edge detection with digital image analysis have been previously reported. The PolyWare programme (Draftware Developers Inc., Vevay, Indiana) is an example of such software and provides a method of assessing the position of the acetabular component on AP radiographs.

The purpose of this study was to evaluate the reliability and accuracy of the two methods of measuring anteversion on plain AP radiographs using Liaw et al’s method and on lateral radiographs using the method of Woo and Morrey compared with that of the PolyWare software on AP radiographs. In addition, we sought to determine the ischial tuberosity angle on lateral radiographs when the anteversion
measured from lateral radiographs using the method of Woo and Morrey is best matched with the anteversion measured from the AP radiograph.

**Materials and Methods**
Between January 2005 and January 2012, 551 patients (294 men and 257 women) undergoing primary THA were enrolled in the study. A posterolateral approach to the hip during which a capsuloplasty was performed was used for all patients. The demographics of the patients, including age, gender, body mass index (BMI), pre-operative diagnosis and American Society of Anesthesiologists (ASA) classification are shown in Table I. A single type of cementless acetabular component (Trilogy, Zimmer, Warsaw, Indiana) was used in all procedures, along with two types of femoral component (Fiber Metal Taper, Zimmer/Heritage cemented, Zimmer, Warsaw, Indiana).

Standardised radiographs, which present controlled rotation and tilt, were used to measure the anteversion of the acetabular component. All images were stored in digital format in the Picture Archiving and Communication System (Impax PACS, Agfa, Antwerp, Belgium). For radiological evaluation, two radiographs were taken: an AP radiograph of the pelvis centred on the symphysis pubis and a cross-table lateral radiograph. Anteversion of the acetabular component was measured on the pelvic AP radiograph using Liaw et al’s method and on the cross-table lateral radiograph using the method of Woo and Morrey (Fig. 1).

For Liaw et al’s method, two measurements are made (S and TL). S is the short axis of the ellipse and TL is the total length of the projected cross-section of the component along the short axis. The short axis (S) is related to the total length (TL) to obtain the S/TL ratio, according to which the anteversion is determined. This ratio is tabulated, and then
Anteversion of the acetabular component can be sought in the corresponding anteversion in a table. Anteversion measured by the method of Woo and Morrey is the angle between a line perpendicular to the horizontal plane and a line tangential to the opening face of the acetabular component. In addition, we measured the ischial tuberosity angle which is the angle between the horizontal plane and the ischial tuberosity on cross-table lateral radiographs (Fig. 2). For this measurement, we drew two lines on the cross-table lateral radiograph. The first line was the reference line which was parallel to the horizontal plane and the second line was towards the long axis of the ischial tuberosity.

The PolyWare programme determines anteversion of the component via edge detection on the AP radiograph (Fig. 3). Using multiple points from the peripheral surface of the component, PolyWare creates an ellipse for the component with a centre that overlaps the centre of rotation and then calculates anteversion using complex mathematical curve-fitting techniques. In this study these values were then regarded as the reference standard anteversion of the acetabular component.

In order to evaluate the accuracy of each method, a single observer (WCS) measured the anteversion using each method on each of the radiographs and calculated mean values and standard deviations (SD). Accuracy was assessed for each of the two manual methods by comparing with the mean value provided by the PolyWare software. The reliability of the measurements was assessed by three observers (WCS, SML, KWL), and each method independently used the same protocol. The intra-observer reliability-defined reproducibility was investigated by one observer (WCS) and was reassessed twice at intervals of two weeks on the images of all 551 patients. The inter-observer reliability of each method was investigated by three observers. All
clinical information about patients and the results of the other observers were concealed.

**Statistical analysis.** In order to check the accuracy of each method on radiographs compared with the PolyWare software, we used a paired t-test. We evaluated intra- and inter-observer reliability for each method using the intraclass correlation coefficient (ICC) with 95% confidence intervals (CI). An ICC of one means perfect reliability and an ICC of zero means the opposite. Statistical analysis was performed with SPSS version 18 (SPSS Inc., Chicago, Illinois) and statistical significance was set at $p < 0.05$.

**Results**

The results are summarised in Table II.

**Accuracy.** The mean overall anteversion of the acetalular component using the PolyWare software was 22.05° (SD 4.44). The mean anteversion using Liaw et al’s method (mean 24.11°, SD 4.43) was similar to the measurement from the PolyWare programme ($t$-test $p = 0.580$). The measurements made by the method of Woo and Morrey (mean 28.33°, SD 8.04) were significantly different from those made by the PolyWare programme or Liaw et al’s method ($t$-test, $p < 0.001$, $p < 0.001$).

**Reliability.** All three methods showed excellent reproducibility with a high ICC value ($> 0.90$), indicating excellent intra- and inter-observer reliability (Table II). With regard to anteversion of the acetalular component on selected qualified cross-table lateral radiographs, in 140 THAs, the mean anteversion using the method of Woo and Morrey was almost the same (within 1°) as that using the PolyWare software. The mean anteversion (22.05°, SD 4.44) was similar to the measurement from the PolyWare programme ($t$-test $p = 0.580$). The measurements made by the method of Woo and Morrey (mean 28.33°, SD 8.04) were significantly different from those made by the PolyWare programme or Liaw et al’s method ($t$-test, $p < 0.001$, $p < 0.001$).

**Discussion**

We analysed three methods for measuring anteversion of the acetalular component on plain radiographs after THA and confirmed that all are consistent and reproducible. We found that Liaw et al’s method was accurate compared with the PolyWare programme, but the method of Woo and Morrey was less accurate.

Achieving the correct orientation of the acetalular component is important in THA. Orientation is usually described in terms of inclination and anteversion, and although inclination may be easily assessed using a plain AP radiograph, measuring anteversion is difficult. In general, the pre-operative measurement of acetalular anteversion is confined to CT or cross-table lateral radiographs, but anteversion after THA can be measured using various methods. The ideal method would be one that is readily available, consistent, reproducible, inexpensive, quick and easy to interpret. Many studies have shown that acetalular anteversion can be measured accurately using CT. However, CT exposes patients to a greater dose of radiation, is more expensive and time-consuming than plain radiographs and is not always routinely available. In addition, CT-measured anteversion represents anatomical anteversion, which is different from the anteversion measured on plain radiographs. Therefore, in theory CT anteversion cannot be used as the reference standard to compare against measurements of radiographic anteversion. Murray may have constructed nomograms, however the measurement from the nomograms is somewhat indirect and complicated and may not give a precise value.

Recent studies with digital image analysis software using edge detection on plain radiographs, such as the PolyWare programme, have accepted such methods as accurate for measuring anteversion of the acetalular component. The PolyWare software has been used to measure wear of polyethylene liners in THA accurately. It creates a best-fit ellipse of the acetalular component from the landmarks which are collected by the user and automatically reconstructs a three-dimensional stereoscopic image from two-dimensional planar images of plain radiographs. The results reflect radiographic anteversion, not the anatomical anteversion of CT measurement. The PolyWare programme also allows the user to input pelvic landmarks to compensate for changes in the position of the pelvis. The usefulness of the PolyWare software has previously been reported. It does not require the patient to be...
exposed to additional radiation. Measurements of anteversion using this software were regarded as the reference standard in our study.

The most widely used and easy plain radiological method for measuring anteversion is that of Woo and Morrey.7 Arai et al23 described a strong correlation between anteversion determined from the cross-table lateral and AP radiographs, although about 5° more anteversion was usually recorded from measurements on the lateral radiograph. Other authors have questioned the reliability and reproducibility of this method.4,25,26 Nunley et al26 noted that variations in serial cross-table measurements were > 10° for 20% of 119 patients, and standardised cross-table lateral radiographs were necessary. Measurements of anteversion from elliptical projection of the acetabular component on AP radiographs have been introduced in various methods since the first report by Visser and Konings in 1981.27 Among the various methods, that of Liaw et al, relatively recently published, takes measurements in an accurate manner.9 They intended to improve the precision of the trigonometric method of Widmer’s18 and concluded that their smaller error implied greater precision.

The differences we have identified between the three methods for evaluating anteversion of the acetabular component can be attributed to the lack of standardisation of the position of the pelvis for the radiographic examination. It has been suggested that anteversion should be measured from standardised radiographs with controlled rotation and tilt.23,26 True lateral radiographs have been referred to as cross-table or shoot-through lateral views that were previously known as the Danelius-Miller29 modifications of the Lorenz view. There is significant variation in the values of anteversion which are measured on serial cross-table lateral views, which should be considered in clinical practice and research.26 Standardising the position of the patient during the performance of radiographs is important to minimise variability in the appearance of anteversion. For these reasons, the long axis of the ischial tuberosity is used as a landmark which is independent of the patient’s position.30 According to our results, when the ischial tuberosity angle was nearly 26° on cross-table lateral radiographs, the anteversion measured using the method of Woo and Morrey was relatively accurate. This is an important point in our results, in that not only should the method of radiological imaging for cross-table lateral radiographs be standardised, but the selection of qualified radiographs is also necessary.

Using an ICC to show the reliability of radiographic measurements between observers, Hing et al31 used an ICC > 0.6 to represent substantial agreement and an ICC > 0.9 to represent excellent agreement, where ICC = 1.0 represents perfect agreement. The intra- and inter-observer reliability for the three different methods of measurement using the ICC ranged from 0.917 to 0.979 in our study, indicating excellent intra- and inter-observer reliability.

There are limitations to this study. First, it was retrospective. We have, however, accounted for all post-operative radiographic outcomes in our consecutive cohort. Secondly, we did not consider the possible effect of pelvic deformity or a poorly visualised or abnormal ischium. In these situations we recognise that CT would be a valuable method of determining anteversion. Nomura et al22 suggested that pelvic CT scans should be reformatted parallel to the functional coronal plane. In this plane, the anteversion measured is the radiographic anteversion. However, using plain radiographs remains the most universally available and economical method for assessment of the orientation of the acetabular component. A contemporary report33 showed that the combination of CT and radiographic information is the most effective tool.

In conclusion, we found that Liaw et al’s method using AP radiographs seemed to be accurate in measuring anteversion of the acetabular component with reference to the anteversion obtained from the PolyWare software. Although the method of Woo and Morrey was less accurate, it evaluates anteversion directly without complicated calculations and reveals whether the component is antverted or retroverted. In addition, when the qualified lateral radiograph was selected, the anteversion measured using the method of Woo and Morrey was relatively reliable.

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