

BIOMEDICAL PAPER

Computerized ellipse method for measuring acetabular version after total hip replacement – a precision study using synthetic and real radiographs

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Abstract

Background: Previous work by our group to address the problem of acetabular positioning based on 2D methods resulted in the development of a measurement method with better precision – Liaw's version. This method may help the early diagnosis of acetabular loosening. In the present study, we hypothesized that our computerized ellipse method could improve the precision of measuring acetabular version.

Methods: We developed our Elliversion software to measure acetabular version. Using total hip replacement (THR) Simulator, 96 radiographs were synthesized with random femoral inclination and 5° to 52° version, half with the femoral head included and half without. These synthetic radiographs and 28 real radiographs were measured with both Elliversion and the trigonometric method twice by one of the authors with a one-week interval between measurements. We then calculated the difference in the repeated measurements. Student's *t*-test was used for statistical analysis of the measuring error and inter-measurement difference.

Results: In the precision study, for synthetic radiographs including the femoral head, the ellipse method was significantly better than the trigonometric method ($p < 0.01$). For synthetic radiographs without the femoral head, there was no significant difference between the ellipse method and the trigonometric method ($p = 0.19$). As for the repeated measurements, for synthetic radiographs including the femoral head, the ellipse method was significantly better than the trigonometric method ($p = 0.001$), whereas for synthetic radiographs without the femoral head, there was no significant difference between the two methods ($p = 0.17$). For real radiographs, there was no significant difference between the two measuring methods ($p = 0.12$). However, if we excluded the four poor-quality radiographs, there was a significant difference between the two measuring methods ($p = 0.04$).

Discussion: We developed a computerized ellipse method for measuring acetabular version on synthetic radiographs and good-quality real radiographs. This method is characterized by its superior precision as compared to the trigonometric method. With the 2D standardized method (Liaw's version), improving the precision of measurement will help earlier diagnosis of acetabular loosening.

Keywords: Total hip arthroplasty, computer aided measurement, acetabular anteversion, acetabular version

Introduction

Measuring the version of the acetabular component after total hip arthroplasty (THA) is important because this parameter can affect the prognosis [1]. Many methods for measuring version have been published to date. These can

be categorized into three groups: the trigonometric method [2–4], the protractor method [1, 5–9], and the computer tomography method [10]. The first two groups are two-dimensional (2D) methods, while the last is a three-dimensional (3D) method.

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The utility of the 2D methods is often questioned because of the positioning problem [11]: The position may cause a difference of up to 13° [11], thus decreasing the value of the methods. In contrast, the 3D method uses computer tomography (CT) and can solve the positioning problem, but the precision is poor because of the low resolution obtained with CT [10].

In our previous work, we developed a mathematical equation to solve the positioning problem for 2D methods [11]:

Radiographic standardized anteversion (Liaw's version)

$$= \arcsin((-h \times \sin \varphi \times \cos \theta + v \times \cos \varphi \times \cos \theta + \sin \theta \times (ssd^2 - h^2 - v^2)^{0.5}) / ssd),$$

where *ssd* is the distance in millimeters from the upper pole of the symphysis pubis to the sacrococcygeal junction; and *h* is the horizontal displacement in millimeters of the sacrococcygeal junction relative to the upper pole of the symphysis pubis in the horizontal direction. We assign *h* to be positive if the sacrococcygeal junction is between the acetabulum and the upper pole of the symphysis pubis; otherwise it is negative. *v* is the vertical displacement in millimeters of the sacrococcygeal junction relative to the upper pole of the symphysis pubis in the vertical direction. We assign *v* to be positive if the sacrococcygeal junction is above the upper pole of the symphysis pubis; otherwise it is negative. θ is the radiographic (planar) anteversion angle, and ϕ is the inclination (abduction) angle [11].

The above equation requires the relative position of two bony landmarks, acetabular version and acetabular inclination. By improving the precision of measurement, we can improve the overall precision. If we can detect small changes in acetabular version, we can detect tiny cup movements earlier, making possible an early diagnosis of acetabular loosening.

Currently, there are several commercial products available for measuring acetabular version by drawing an ellipse to fit the outer edge of the cup. One example is OrthoViewTM (OrthoView, Southampton, UK). However, these products are neither economical nor available everywhere. Moreover, there has been no precision study of these "ellipse" methods.

As such commercial products are not available at our hospital, we developed our own software for measuring acetabular version in order to conduct a precision study. We hypothesized that the digitalized method would improve the precision of measuring acetabular version, since the error and intra-observer difference may both be decreased with a computerized method.

Methods

In our previous work, we provided detailed definitions and described the measurement of acetabular version [1]. In our opinion, radiographic (planar) version is suitable for measurement. Also, according to the equation of McLaren [12],

Radiographic version = \arcsin (short axis/long axis)

where the short and long axes are axes of the elliptical outline of the acetabular shell.

In most cases, the ellipse is obscured by the femoral head, making measurements difficult. However, if we are able to draw the entire ellipse for measurement, we can easily estimate the obscured portion of the ellipse, and can then improve our precision.

On the Microsoft Windows platform, we developed our Elliversion software to measure version. Our software can upload many image file formats, including BMP, JPG, DCM, and so on. The user can apply an ellipse to the acetabulum and then adjust the ellipse by altering the long and short axes.

As we were unable to draw the curves directly, we separated the ellipse into 64 parts. In other words, the ellipse was formed by 64 lines, and is drawn as a 64-sided polygon. Every endpoint of the lines was calculated by the position and length of both the long and short axes. The user can adjust the long and short axes to fit the ellipse formed by the outer shell of the acetabular component.

To verify the software, we synthesized 96 radiographs with random inclination and 5° to 52° version using total hip replacement (THR) Simulator [13]. THR Simulator is software for synthesizing radiographs of THR with varying parameters, such as acetabular radiographic version, inclination, acetabular size, acetabular thickness, and head size. The software can be downloaded freely [13]. In this study, half of the synthesized radiographs included the femoral head and half were without it (Figure 1).

These synthetic radiographs and 28 real radiographs were each measured with both Elliversion and the trigonometric method. Measurements were performed twice by the same individual, with a one-week interval between measurements (Figures 1–3). We then calculated the difference between the repeated measurements and the absolute error. If conditions were not well adjusted when taking the radiographs, we could only see the outer-lower part of the ellipse, with the inner-upper parts being invisible. This inability to see the entire ellipse may result in bigger differences between the measurements. We defined radiographs of this kind as poor-quality radiographs, and analyzed the data again

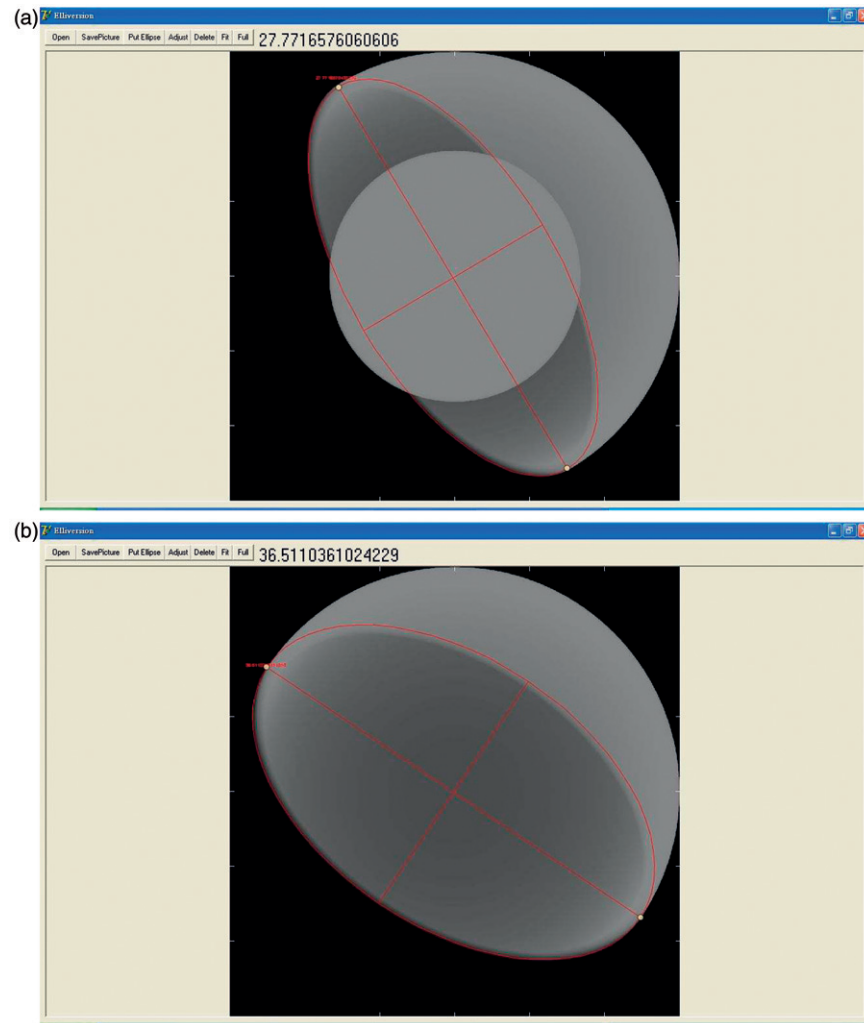


Figure 1. Synthetic radiographs with (a) and without (b) the femoral head. Acetabular version was measured using Elliversion. The user can read the version from the upper label.

after excluding the four poor-quality radiographs (Figure 3).

Student's *t*-test was used for statistical analysis of the measuring error and inter-measurement difference.

Ethical approval

This study was approved by the Institutional Review Board of Tao-Yuan General Hospital (TYGH098019).

Results

Table I presents the results of the precision study. For synthetic radiographs including the femoral head, the absolute error for the ellipse method ranged from 0° to 0.98°, with a mean \pm SD of 0.28 ± 0.21 ; for the trigonometric method, the range was 0° to 2.06°, and the mean was 0.73 ± 0.45 . There was a significant difference

Table I. Absolute error of measurements for synthetic radiographs using the ellipse and trigonometric methods.

Measurement	Min. error	Max. error	Mean	SD	<i>p</i> -value
Ellipse with femoral head #1 & #2*	0	0.98	0.28	0.21	<<0.01
Trigonometric with femoral head #1 & #2*	0	2.06	0.73	0.45	
Ellipse without femoral head #1 & #2	0.01	1.24	0.32	0.21	0.19
Trigonometric without femoral head #1 & #2	0	1.02	0.29	0.19	

#1 & #2: We combined the calculated error of the first and second measurements.

*Statistical difference.

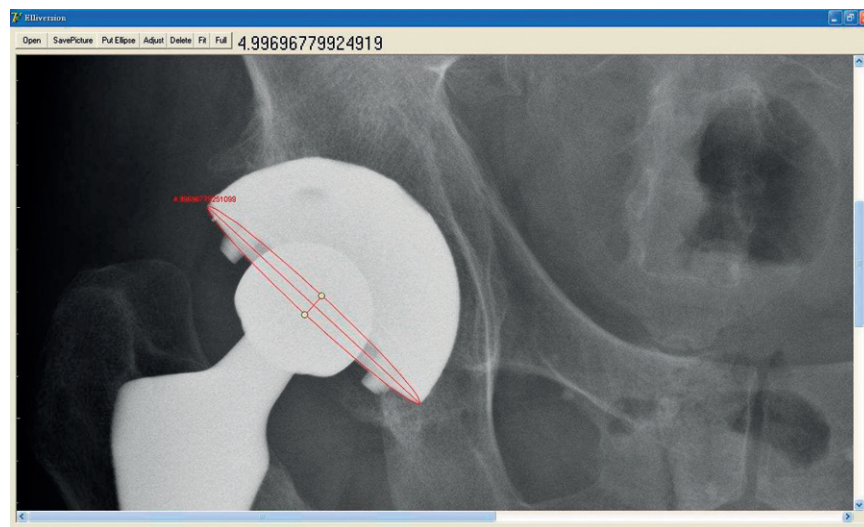


Figure 2. Post-operative radiograph of a United right total hip arthroplasty. Acetabular version was measured using Elliversion.

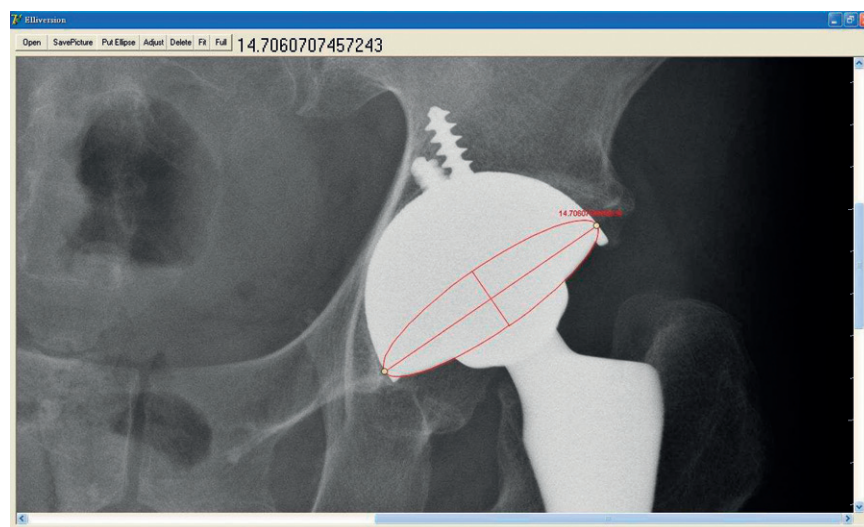


Figure 3. Post-operative radiograph of a United left total hip arthroplasty. Acetabular version was measured using Elliversion. In this case, half of the ellipse is not visible, and we could only assume the shape. This results in a bigger difference between the measurements. We defined radiographs of this kind as poor-quality radiographs.

between the ellipse method and the trigonometric method in this group ($p < 0.01$). For synthetic radiographs without the femoral head, the absolute error of the ellipse method ranged from 0.01° to 1.24° , with a mean of $0.32 \pm 0.21^\circ$; for the trigonometric method, the range was 0° to 1.02° , and the mean was $0.29 \pm 0.19^\circ$. There was no significant difference between the ellipse method and the trigonometric method in this group ($p = 0.19$).

Table II presents the results of the repeated measurement study. For synthetic radiographs including the femoral head, the absolute difference for the ellipse method between the two

measurements ranged from 0.03° to 1.44° , with a mean of $0.33 \pm 0.31^\circ$. For the trigonometric method, the absolute difference between the two measurements ranged from 0.06° to 2.19° , with a mean of $0.56 \pm 0.43^\circ$. The absolute difference was significantly different between the two measurements ($p = 0.001$). For synthetic radiographs without the femoral head, the absolute difference for the ellipse method between the two measurements ranged from 0° to 0.88° , with a mean of $0.24 \pm 0.19^\circ$. For the trigonometric method, the absolute difference between the two measurements ranged from 0.01° to 1.41° , and the mean was $0.26 \pm 0.28^\circ$. There was no significant difference

Table II. Absolute difference for the repeated measurements.

Measurement	Min.	Max.	Mean	SD	p-value
Ellipse with femoral head #1 & #2	0.03	1.44	0.33	0.31	0.001
Trigonometric with femoral head #1 & #2	0.06	2.19	0.56	0.43	
Ellipse without femoral head #1 & #2	0	0.88	0.24	0.19	0.17
Trigonometric without femoral head #1 & #2	0.01	1.41	0.26	0.28	
Ellipse real #1 & #2	0.01	1.89	0.44	0.43	0.12
Trigonometric real #1 & #2	0.01	2.11	0.58	0.55	
Ellipse (good*) real #1 & #2	0.01	0.78	0.30	0.24	0.04
Trigonometric (good*) real #1 & #2	0.01	2.11	0.52	0.53	

good* = after exclusion of the four poor-quality radiographs.

between the two measurements ($p=0.17$). For real radiographs, the absolute difference between the two measurements using the ellipse method ranged from 0.01° to 1.89° , with a mean of $0.44 \pm 0.43^\circ$. For the trigonometric method, the absolute difference between the two measurements ranged from 0.01° to 2.11° , and the mean was $0.58 \pm 0.55^\circ$. There was no significant difference between the two measuring methods ($p=0.12$). However, if we excluded the four plain radiographs of insufficient quality, there was a significant difference between the two measuring methods ($p=0.04$).

Our results showed that the ellipse method had better precision than the trigonometric method for synthetic radiographs including the femoral head ($p<0.01$). In synthetic radiographs without the femoral head, the accuracy of both methods showed no statistical difference ($p=0.19$). The ellipse method also showed less inter-measurement difference on good-quality radiographs.

Discussion

Computer aided surgery has become increasingly prevalent in recent years. However, we believe that computer aided post-operative evaluation is as important as intra-operative introduction of artificial intelligence, if not more so, in improving clinical outcomes and long-term patient satisfaction.

The results of this study confirmed our hypothesis that the ellipse method offered better precision compared to the trigonometric method. In radiographs including the femoral head, the femoral head

obscures the edge, and the ellipse method performed better in such cases. In radiographs without the femoral head, however, version could be measured directly using the trigonometric method, so the ellipse method offered no advantage.

For plain radiographs, there was no statistically significant difference between the two measuring methods, although there was a tendency for our ellipse method to have better precision. However, if we excluded the four plain radiographs with poor quality (Figure 3), we could measure more accurately using our method ($p=0.04$).

Some orthopaedic surgeons may question the value of precisely measuring the acetabular version. As mentioned earlier, if we have a precise method for measuring version, we may have a smaller least significant change for Liaw's version. We can detect tiny cup movements more easily, making earlier detection of cup loosening possible.

For precise measurement of a prosthesis, radio-stereometric analysis (RSA) is a good option [14], being able to achieve a precision of $30 \mu\text{m}$. However, RSA requires the attachment of special tantalum markers to the prosthesis during the manufacturing process, and to the patient during the operation, which is impractical for everyday clinical use. RSA also requires special software which is expensive and not available in every country.

For digital radiograph systems, the vendors always offer orthopaedic suit software as an option for customers. This orthopaedic suit software usually provides the ellipse method for measuring acetabular version, as in the OrthoViewTM software (OrthoView, Southampton, UK), and the ellipse method is thus readily accessible in most countries.

Conclusions

We developed our own ellipse method for measuring acetabular version. We have proven it to be more precise than the well-accepted trigonometric method for use with synthetic radiographs and good-quality plain radiographs. The method can be further used in measurements which require precision, such as determination of Liaw's version.

Declaration of interest

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Notice of Correction

The version of this article published online ahead of print on 25 Mar 2013 contained an error on page 1. The first author, Chen-Kun Liaw, should have been affiliated with affiliations 1, 2 and 3 and the third affiliation should have read “Ming Chuan University, Tapei City, Taiwan”. The errors have been corrected for this version.