Radiographic assessment of component orientation in elbow arthroplasty

A technical description

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We describe an alternative method of taking standardized radiographs of the elbow in patients with rheumatoid arthritis, taking into account fixed deformities. The technique enables assessment of the orientation of joint replacement components, including their axial rotational alignment. The accuracy of the method for calculating axial rotational alignment has been evaluated using a skeleton model. Within the 20° limits of arm position the accuracy was found to be on average 1.4° for the humerus and 2.2° for the ulna.

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The correct positioning of joint replacement components is important for function, stability and long term success. Figgie et al. (1986) have shown that for linked total elbow replacement, the accurate positioning of the center of rotation is associated with less postoperative complications. Their radiographic technique, however, depended upon obtaining comparable views to those taken preoperatively, and did not take into consideration the axial rotational position of the prostheses.

We have devised an alternative technique because the flexion contracture and restriction of supination usually found in rheumatoid elbows does not permit the usual standard radiographs. The method, in addition, allows calculation of the axial rotational alignment of joint replacement components. This paper describes the technique and reports the results of a study to evaluate its accuracy using a skeleton model.

Methods

Radiographic technique

The patient's arm is positioned on a specially designed jig with the humerus horizontal, the elbow flexed to 45°, and with the forearm midprone in the vertical sagittal plane (Figure 1). The jig is designed to support the arm in this position and allows placement of x-ray cassettes underneath, first horizontally and then at 45°, without moving the patient's arm. 2 AP radiographs are taken with the tube to film distance at 100 cm. The first is vertical, centered at the epicondyles and gives a true AP of the humerus and a foreshortened view of the forearm (the humeral AP). The second is angled at 45°, centered at the epicondyles, and in the same vertical sagittal plane passing through the forearm and humerus, and provides a true AP of the forearm and a foreshortened view of the humerus (the forearm AP). A lateral radiograph is then taken at 90° to the 2 AP views, again centered at the epicondyles. The humeral AP and the forearm AP radiographs provide appropriate views for assessing the valgus position of the

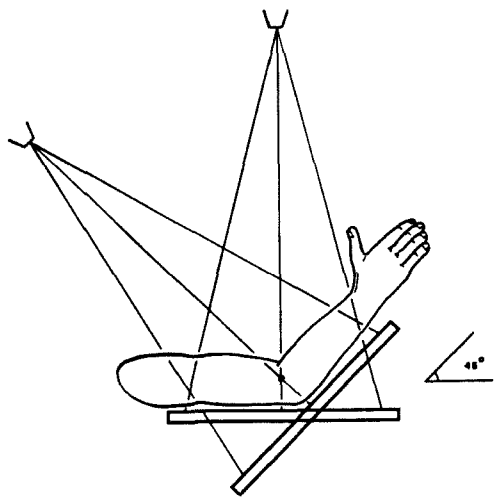


Figure 1. The arm positioning and placement of XR cassettes for taking the two anteroposterior radiographs. In both instances the XR tube is centered at the level of the lateral epicondyle and the tube to film distance maintained at 1 meter.

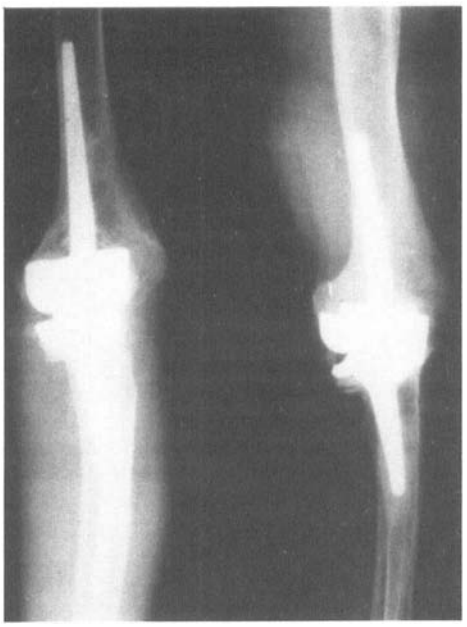
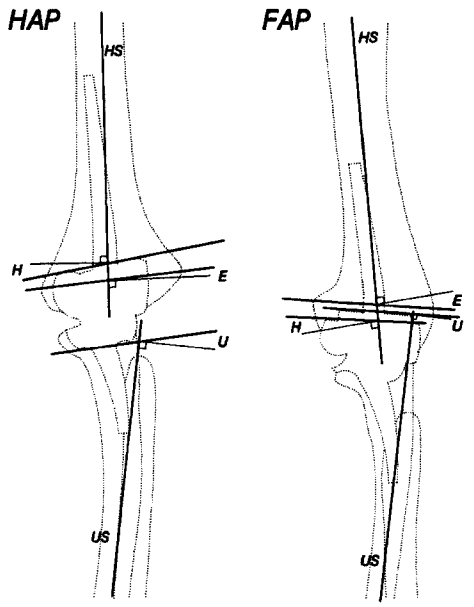


Figure 2. Humeral AP (HAP_1 left) and forearm AP (FAP_1 right) radiographs of a patient with a capitello-condylar prosthesis.



The valgus angle of the humeral component (H) is measured against the humeral shaft (HS) and the ulnar component valgus (U) with the ulnar shaft (US). The points on the medial and lateral epicondyles with the greatest perpendicular distance from the humeral shaft are marked and a line drawn between them. The valgus angle of this epicondylar line (E) is measured against the humeral shaft.

humeral and ulnar components of a total elbow replacement, respectively (Figure 2).

The humeral and ulnar shafts are defined on both AP radiographs. The valgus angles of the articular part of the humeral component, and of a line drawn between the epicondyles, are measured with respect to the humeral shaft on the humeral AP, and the apparent valgus angles on the forearm AP. The valgus angle of the ulnar component with respect to the ulnar shaft is measured on the forearm AP and the apparent valgus on the humeral AP.

The valgus and the apparent valgus angles of the components provided on the two radiographs can be used to calculate the rotational alignment of the components. The equation for the humeral component is:

$$\tan H_{AX} = \tan H_{HAP} - \sqrt{2}.\tan H_{FAP}$$

where H_{AX} is the axial rotational angle with respect to the plane of the horizontal x-ray plate, H_{HAP} is the humeral valgus angle on the humeral AP radiograph, and H_{FAP} is the apparent valgus angle of the humeral component on the forearm AP radiograph. The derivation of this equation is given below.

A similar equation applies to the epicondylar plane:

$$\tan E_{AX} = \tan E_{HAP} - \sqrt{2} \tan E_{FAP}$$

where the axial rotational position of a line drawn between the epicondyles is calculated. It is a simple subtraction to determine the axial rotational angle of the humeral component in relation to the epicondyles.

Another equation can be used to determine the axial rotational position of the ulnar component with respect to the plane of the 45° x-ray plate:

$$\tan U_{AX} = \tan U_{FAP} - \sqrt{2} \tan U_{HAP}$$

Arithmetically the valgus angles are regarded as positive and varus angles as negative. Similarly internal rotation is positive and external rotation is negative.

Skeleton study

In order to evaluate the accuracy of calculation of the axial rotational alignment a skeleton study was devised. A cadaveric elbow was disarticulated and prepared to accept a 15° valgus capitello-condylar (Johnson and Johnson Orthopaedic Ltd.) humeral component and a standard ulnar component.

The humeral component was inserted in 3 different rotational alignments: (1) in line with the epicondyles; (2) internally rotated; and (3) externally rotated. The humerus was mounted and then positioned horizontally on the jig and radiographed, taking the two AP views, with the epicondyles: (a) horizontal; (b) 20° internally rotated; and (c) 20° externally rotated, for

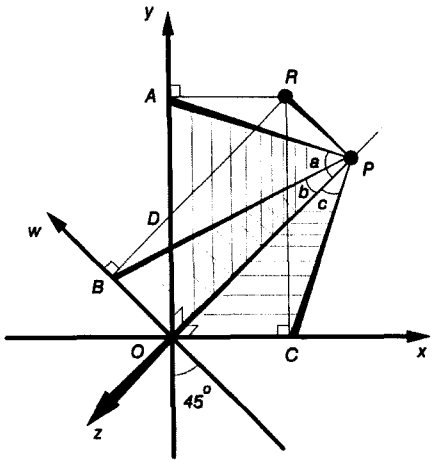


Figure 3. Trigonometric calculations.

each of the component positions. The axial rotational position of the humeral component in relation to the epicondyles was calculated for each of the nine positions and compared with the axial rotational position measured on axial radiographs taken for each of the component positions.

The ulna was prepared by initially placing a Kirschner wire transversely through the ulna shaft in the coronal plane. This was used as a radiographic marker with which to compare rotational alignment of the ulnar component. The ulnar component was inserted: (1) parallel to the wire; (2) internally rotated; and then (3) externally rotated. The ulna was then mounted and positioned on the jig on the 45° slope and this time the two AP radiographs were taken with the ulna shaft lying: (a) in the vertical sagittal plane; (b) 20° away from the vertical imitating internal rotation at the shoulder; and (c) 20° away from the vertical imitating external rotation at the shoulder, for each of the component positions. The Kirschner wire remained parallel to the 45° x-ray plate at all times. The axial rotational position of the ulnar component in relation to the Kirschner wire was calculated for each of the 9 positions and compared with the axial rotational position measured on axial radiographs taken for each of the 3 component positions.

Calculations

The principle of the trigonometry is to define the angle of a line P–R (Figure 3) in terms of its projection on to a vertical plane (angle *a*), a horizontal plane (angle *c*), and on to a plane at 45° to both (angle *b*). If the y-axis is considered to be in line with the humeral shaft, the z-axis (perpendicular to the page) transverse to the humeral shaft in the coronal plane, and the x-axis in line with the XR beam for taking the humeral AP radiograph, then angle *a* could be the valgus angle of the humeral component and angle *b* the apparent valgus angle seen on the 45° or forearm AP radiograph. Angle *c* would therefore be the axial rotational angle. We need to define angle *c* in terms of angles *a* and *b*. The w-axis lies at 45° to the x- and y-axes, and 90° to the z-axis.

Consider initially the projections of the point R on to the axes.

For R: $y = A$; $x = C$; $w = B$.

The projection of the point R on to the w-axis crosses the y-axis at the point D. The equation for this line in terms of y and x is:

$$x = y - D$$

By Pythagoras:

$$D^2 = B^2 + B^2 \text{ or: } D = \sqrt{2}\,B$$

Because for the point R the values for y and x are defined, then the above equation for x becomes:

$$C = A - D = A - \sqrt{2}\,B$$

The distances A, B and C from the point O are proportional to the tangents of the angles a, b, and c, thus:

$$P \tan c = P \tan a - P\sqrt{2} \tan b$$

The constant P can be eliminated:

$$\tan c = \tan a - \sqrt{2} \tan b$$

The rotational angle *c* can therefore be calculated from the measured angles *a* and *b* on the two radiographs.

Results

The average error for all positions, when compared with the measured axial rotation on the axial radiographs, was 1.4° for the humerus and 2.2° for the ulna (Table 1). The average error was least if the humerus was 20° internally rotated and if the ulna shaft was vertical in the sagittal plane.

The use of markers on the epicondyles reduced the average error for calculating humeral rotation by 50 percent (results not shown), but initial attempts to use epicondylar markers on patients has proved unreliable. No difference was found between valgus angles measured from the superior or inferior borders of the components.

Discussion

The radiographic technique presented offers standardized views of rheumatoid elbows from which comparisons and measurements can be made. Valgus align-

Table 1. The axial rotational position of the components calculated for three component positions in three arm positions and compared with the position measured on axial radiographs taken for each of the component positions

Component position	Rotational position (degrees)			
	Measured on axial radiographs	Calculated with arm rotation		
		Neutral	Internal	External
Humerus				
Neutral	+1	+1	0	+1
Internal rotation	+15	+13	+16	+14
External rotation	−18	−21	−18	−23
Mean error		1.7	0.6	2.0
Ulna				
Neutral	0	0	+1	−5
Internal rotation	+17	+19	+16	+12
External rotation	−16	−17	−12	−17
Mean error		1.0	2.0	3.7

ment can be judged accurately on the respective views. The majority of patients with symptomatic elbows are unable to fully extend their elbows or to fully supinate the forearm which are requirements for the usual AP radiograph. The technique also provides the ability to calculate rotational alignment of the components with an acceptable accuracy within the limits of 20° of external to 20° internal rotation of the shoulder. It was noted that the errors were larger on average for both the humerus and the ulna in the externally rotated position. That this should be so can be explained by the fact that the projectional distortion of angles (by the cone-shaped beam of x-rays) of valgus aligned implants onto both x-ray plates is maximal when the implants are positioned in external rotation.

The majority of rheumatoid patients have restriction of shoulder external rotation and so this position will usually be avoided. In addition, with the forearm vertical in the sagittal plane, the epicondylar plane normally lies slightly internally rotated as the medial epicondyle lies posteriorly, thus fortuitously further reducing the calculation error in determining humeral component axial rotation.

The lack of suitable reliable bony landmarks in the proximal ulna means that without radiographic markers the rotational alignment of the ulnar component can only be made in relation to the plane of the 45° x-ray plate. The method assumes that the axial rotation of the ulna itself is normal, which explains our choice of the midprone position for the radiographs.

The technique is relatively simple and soon learnt by the radiographers. The analysis is a little time consuming but the use of more sophisticated and expensive imaging techniques is avoided. It is important that the same humeral and ulnar shafts are defined on the two AP radiographs, and the present technique now uses external markers to aid with this. This study revealed the importance of incorporating an x-ray marker which is known to be parallel to both x-ray plates, particularly for evaluation of the ulnar component.

Acknowledgements

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Reference

Figgie H E, Inglis A E, Mow C. A critical analysis of alignment factors affecting functional outcome in total elbow arthroplasty. J Arthroplasty 1986; 1 (3): 169–73.