The effect of the offset humeral head on the micromovement of pegged glenoid components

A COMPARATIVE STUDY USING RADIOSTEREOMETRIC ANALYSIS

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In a prospective study between 2000 and 2005, 22 patients with primary osteoarthritis of the shoulder had a total shoulder arthroplasty with a standard five-pegged glenoid component, 12 with non-offset humeral head and ten with offset humeral head components. Over a period of 24 months the relative movement of the glenoid component with respect to the scapula was measured using radiostereometric analysis.

Nine glenoids needed reaming for erosion. There was a significant increase in rotation about all three axes with time ($p < 0.001$), the largest occurring about the longitudinal axis (anteversion-retroversion), with mean values of 3.8° and 1.9° for the non-offset and offset humeral head eroded subgroups, respectively. There was also a significant difference in rotation about the anteversion-retroversion axis ($p = 0.01$) and the varus-valgus ($p < 0.001$) z-axis between the two groups. The offset humeral head group reached a plateau at early follow-up with rotation about the z-axis, whereas the mean of the non-offset humeral head group at 24 months was three times greater than that of the offset group accounting for the highly significant difference between them.

Replacement of the shoulder is firmly established as a reliable method of treatment for a variety of conditions affecting the joint.¹⁻⁸ Loosening of the glenoid component remains a considerable concern since radiolucent lines are often seen on the initial post-operative films and at follow-up.^{9,10} Little is known about the mechanism of this loosening. One large series described significant differences in glenoid lucency around keeled and pegged components.⁵ Other factors which may also be important are the size and position of the replacement of the humeral head.

Early prosthetic systems used a single radius of curvature for the humeral head with a matching radius of curvature of the glenoid.¹¹ That of the humeral head and the length of the humeral neck determine the dimensions of the articular surface of the head. Although these parameters vary widely among individuals, the ratio of the diameter of the head to the length of the neck is fairly constant.¹² In anatomical studies, the humerus has been shown to have a combined offset to the longitudinal axis of the humerus both posteriorly and medially¹³ and, as a consequence, modular humeral components which are adaptable to the individual anatomy have been developed. These attempt to restore the original three-dimensional geometry of the proximal humerus. The effect

of these offsets on the longevity of the glenoid component and on the clinical outcome is not known.

Our study was designed to determine the effects of offset of the humeral head on the micromovement of standard five-pegged glenoid components by using radiostereometric analysis (RSA)¹⁴ to measure the position of rigid bodies in three dimensions and to compare this early movement with that of a series of comparable implants in which a non-offset humeral head had been used. A secondary aim was to describe the early movement of the glenoid components using exploratory principal-component analysis¹⁵ which can be used to indicate implants at risk.

Patients and Methods

In a prospective study between 2000 and 2005, 30 patients with primary osteoarthritis who had a total shoulder arthroplasty were studied by RSA. A total of 15 patients had a non-offset humeral head before 2003¹⁴ and 15 an offset humeral head after that date. Approval of the ethical committee had been obtained and the patients gave informed consent. Good glenoid bone stock, sufficient to introduce a glenoid component, and an intact and functioning rotator cuff were required. A total of eight patients was excluded from the study including

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Table I. Distribution of head size and depth for the non-offset humeral head (NOHH) and offset humeral head (OHH) groups

Diameter of the humeral head (mm)	NOHH depth			OHH depth		
	S	M	L	16	18	21
40	1	3	0	0	1	0
44	0	2	1	1	2	1
48	0	3	0	0	3	1
52	0	0	1	0	0	1
56	0	0	1	0	0	0

three who died, two who withdrew because of failing health before the end of the study, two who had unstable placement of the marker beads and one in whom the glenoid component could not be clearly visualised. This left 22 patients in the study. The non-offset humeral head group had a male-to-female ratio of 4:8 with a mean age of 69 years (58 to 84). In the offset humeral head group the male-to-female ratio was 3:7 and the mean age was 65 years (60 to 80).

Operative technique. The operations were undertaken by two of the authors (IAT, JFH) in a standardised fashion. The patients were placed in the beach-chair position and a deltopectoral approach was used. None had deltoid release, although most had a partial release of pectoralis major. The biceps tendon was present in all but one patient and the rotator cuff in all. Supraspinatus was found to be thinned but intact in two patients. An anterior and inferior capsular release was carried out. Preparation of the glenoid and humerus was undertaken as described in the manufacturer's guidelines. Any residual soft-tissue remnants such as labral remnants were removed from the glenoid. A central hole was then defined and using the appropriately sized reamer any remaining cartilage was removed. Any erosion was corrected by tilting the reamer appropriately. The glenoid was then drilled to allow insertion of the five-pegged component which was cemented into place. The Global shoulder arthroplasty system (DePuy International, Leeds, United Kingdom) was used in all cases. The humeral components were inserted uncemented in 30° of retroversion. The size of the humeral head was correlated with the dimensions of the excised head allowing appropriate soft-tissue balance. In the first group the heads were not offset and in the second they were generally offset posterosuperiorly. The range of head size for each group is shown in Table I. With the Global system there is a difference of 6° in the diameter of curvature between the humeral and glenoid components. Post-operatively, all patients began a passive and supervised early active mobilisation programme.

The glenoid bone stock was assessed by either axial plain radiographs or a CT scan, as well as during the operation. The rotator cuff was assessed both clinically and during surgery both visually and by palpation. At the time of operation, six glenoids in the non-offset group and three in the

offset humeral head group were eroded and required corrective reaming. Using the classification of Walch et al,¹⁶ the erosions in the former group were classified as anterior in three and type B1 in three. In the offset humeral head group there were two anterior erosions and one type B1. Clinical evaluation included assessment of pain on a visual analogue scale, movement in all planes, strength and function. This allowed calculation of the Constant-Murley¹⁷ and American Shoulder and Elbow Surgeons (ASES) scores.¹⁸ Assessments were undertaken pre-operatively and at the time of the radiological review at follow-up.

RSA technique. At operation, tantalum beads (1 mm) were inserted into the scapula, typically with two in the acromion, two in the glenoid and one in the coracoid. The beads were inserted using a drill and a special delivery system. Beads were also inserted into the pegs of the implant.¹⁴ Stereo pairs of radiographs were obtained using the uniplanar UmRSA Table 43 (RSA Biomedical, Umea, Sweden). RSA radiographs were taken post-operatively and after three, six, 12 and 24 months. They were digitised and analysed using the UmRSA digital version 5 system (RSA Biomedical). The relative movement of the glenoid component with respect to the scapula was measured. The UmRSA system predefines linear movement as translation along the following axes: transverse (x-axis, mediolateral translation), longitudinal (y-axis, proximodistal translation) and sagittal (z-axis, anteroposterior translation). Similarly, rotation is defined about the three axes: transverse (x-axis, anteroposterior), longitudinal (y-axis, anteversion-retroversion) and sagittal (z-axis, varus-valgus). The technique of RSA of the glenoid has been described previously,¹⁴ and has been shown to be reproducible and accurate with the longitudinal axis having the largest critical level ($p < 0.05$) for translation equal to 0.13 mm and rotation equal to 1.2°. **Statistical analysis.** Clinical outcome measures were examined by use of a paired *t*-test on pre- and post-operative measures. Absolute RSA measurements were analysed using parametric methods.^{14,19} Differences in the early rates of loosening for translation and rotation of the centroid between implants were determined by using analysis of variance (ANOVA). The within-subject factor was follow-up at three, six, 12 and 24 months, and two between-subject factors were the offset or non-offset humeral head

Table II. Mean values of movement and shoulder scores before and after operation for the two groups. Pain was measured using a 10 cm visual analogue scale. Movement was measured in degrees except for internal rotation, which was measured on the Constant-Murley ten-point scale. The American shoulder and elbow surgeons (ASES) and Constant-Murley scores ranged from 0 to 100

Diameter of the humeral head (mm)	NOHH*		OHH†	
	Pre-operative	Post-operative	Pre-operative	Post-operative
Pain	5.8	0.8	7.4	0.8
Abduction	65	103	57	102
Flexion	78	116	72	117
ASES score	33	88	26	82
Constant-Murley score	29	61	23	71

* NOHH, non-offset humeral head

† OHH, offset-humeral head

Table III. Mean values (°) of rotation of rigid body in three dimensions for the standard five-pegged glenoid component and analysis of variance comparing micromovement with time for the two groups, according to the treatment for glenoid erosion at the time of operation

				Time (mths)				p-value		
	Component*	Erosion	Number	3	6	12	24	Within time	Between component	Between erosion
Mean rotation										
Anterior/posterior (x)	NOHH	No	6	0.8	0.9	0.8	0.8			
	NOHH	Yes	4	0.2	1.0	1.0	1.0			
	OHH	No	7	0.7	1.0	0.6	0.7			
	OHH	Yes	3	0.2	0.4	0.6	0.2	< 0.001	0.19	0.03
Ante/retroversion (y)	NOHH	No	6	1.1	0.9	1.0	1.7			
	NOHH	Yes	4	1.1	2.6	2.6	3.8			
	OHH	No	7	0.9	0.7	1.8	1.9			
	OHH	Yes	3	0.4	0.4	0.9	0.8	< 0.001	0.01	0.30
Varus/valgus (z)	NOHH	No	6	0.7	1.3	1.6	1.8			
	NOHH	Yes	4	0.5	1.1	1.8	2.6			
	OHH	No	7	0.8	0.6	0.9	0.9			
	OHH	Yes	3	0.4	0.7	0.9	0.8	< 0.001	< 0.001	0.96

* NOHH, non-offset humeral head; OHH, offset humeral head

groups and the presence or absence of glenoid erosion. RSA studies can report absolute or signed data^{19,20} which do not have to be mutually exclusive. Signed RSA measurements²⁰ were analysed using principal-component analysis of the six parameters of movement of the glenoid segment. This multivariate technique has previously been applied to the glenoid and identifies linear associations between the six degrees of freedom of centroid movement and produces summary components which are orthogonal to each other.¹⁴ The principal-component analysis produces coordinates for the whole dataset and these can provide a clear indication of the implants at risk as well as describing the complex movements occurring over time.

Results

The clinical outcome for all patients is shown in Table II. With a minimum follow-up of two years the pain scores, the range of movement, the Constant-Murley score, and the self-assessed ASES score all improved significantly (paired *t*-test, $p < 0.001$) for both groups of patients. There was no significant

difference in clinical outcome between the two groups. The offset group had a mean Constant-Murley score which was ten points greater than that of the non-offset group.

The ANOVA results of the glenoid rigid-body rotations are shown in Table III. There was a significant increase in rotation about all three axes over time. The largest rotations occurred about the longitudinal axis (anteversion-retroversion) with mean values of 3.8° and 1.9° for the non-offset and offset humeral head eroded subgroups, respectively. There was also a significant difference in rotation between the former and latter groups about the anteversion-retroversion axis ($p = 0.01$) and most notably about the varus-valgus ($p < 0.001$) axis. The mean rotation about the z-axis is shown in Figure 1 in which the offset humeral head group reached a plateau early in follow-up and showed a small 95% confidence interval (CI). The mean of the non-offset humeral head group at 24 months was three times greater than that of the offset group accounting for the highly significant difference between the groups as shown in Table III.

Fig. 1

Graph showing the mean rotation about the z-axis (varus/valgus tilt) over time for the two groups. The error bars show the 95% confidence intervals.

Fig. 2

Principal-component (PC) co-ordinate graph showing the full radio-stereometric analysis dataset.

Most glenoid components from both groups initially moved and then reached a plateau by 24 months. There were, however, two notable exceptions, both in the non-offset group. In one patient a glenoid component had perforated the cortical bone at the time of surgery and in another who had resumed heavy lifting, superior subluxation developed.

Principal-component analysis was performed on all of the dataset. The first component accounted for 43% of all variations and was dominated by three linear interactions, namely anteversion/retroversion about the y-axis together with varus rotation and translation about the z-axis. The second component, unrelated to the first, accounted for 19% of all residual variation and was composed of a linear interaction between anterior/posterior tilt about the x-axis and translation along the y-axis. The principal component co-ordinate plot of the whole dataset obtained from this analysis is shown in Figure 2.

The principal co-ordinate score has zero mean and unit variance and can be considered to be similar to a z-score with outliers indicated when the score is greater than two. Five non-offset humeral head components had a score greater than two, but no offset components. The two non-offset components which had continued to move had scores greater than five which suggested that these implants were at risk.

Discussion

Aseptic loosening of a glenoid component is a common complication of total shoulder replacement in the medium to long term.^{9,21-23} While there is a disparity between the incidence of radiolucent lines around glenoid components

and the rate of revision, there is increasing evidence that these lines become more pronounced with time.^{2,24-26} Overall, it appears that loosening of the glenoid is inevitable and will, if the patient survives, lead to the onset of further symptoms. The factors affecting loosening of the glenoid are numerous²⁷ and include the design of the component, surgical technique of preparation of the glenoid and cementing, the shape and position of the humeral component and other factors. Both clinical and RSA studies have previously shown the advantage of the pegged over the keeled component.^{9,14,28}

Replacement of the head of the humerus in an anatomical position may have an effect on the glenoid component. Our study compared two groups of patients one of which had a non-anatomical replacement of the humeral head and the other an anatomical replacement using an offset head. The smallest movement occurred about the x-axis in both groups, the pegged design controlling rotation about this axis. Our results clearly showed less micromovement with a more anatomical humeral head about the z-axis with a highly significant difference between the two groups; this was not observed about the y-axis. The reason for this remains unclear although it may be that the offset head, while improving the anatomy of the replacement does not address tilt. Improvements in the design of the humeral head now allow correction for version, offset and tilt.

Our study also showed that the use of a more anatomical head did not appear to confer an improved range of movement. This was a surprising finding although our samples

are small. The ten-point difference in Constant score was not statistically significant, however, the power of the *t*-test was only 0.3 indicating a type-2 error. Each group would require to have 33 patients to obtain a power of 0.8.

The correction of glenoid erosion appears to have a detrimental effect on glenoid movement. Glenoids which are inserted after a surgical correction for erosion seem to migrate more than those which do not need this, as has been noted previously.^{4,14} The reason remains unclear. It would seem logical that correct realignment of the glenoid component would improve its survivorship. One explanation of our finding may be that this correction was done manually by the naked eye. While there was thought to be some improvement, this could not be quantified. In order to assess this the patient would need to undergo CT to determine the glenoid version before and after insertion of the prosthesis using the techniques described by Nyffeler et al.²⁹

We have used principal-component analysis which makes maximum use of signed data in describing summary patterns of micromovement for all six degrees of freedom of movement. The principal component co-ordinates of the dataset were used to produce an at-risk index in chart form as shown in Figure 2. The pattern of migration of each glenoid can easily be seen at a glance using this method. The wandering arrows in Figure 2 describe the migration patterns of five non-offset humeral head glenoid components, two of which seem to be at risk and are labelled in the figure as operations 352 and 437.

With further improvements in the design of the glenoid component, better preparation and cementing, with management of the humeral head and surrounding soft tissues, the survivorship of glenoid components in total shoulder replacement will continue to improve. Further designs of the glenoid component should fully address the pleomorphic nature of the glenoid notch,^{12,30} specifically its pear-drop rather than circular shape.

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