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ORIGINAL ARTICLE

An in vivo kinematic study of the reverse shoulder joint replacement

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Abstract As of now few studies have investigated the kinematics of the reverse shoulder arthroplasty (RSA) in patients and none on how this may be affected by glenosphere shape or size. There have been a few biomechanical studies evaluating the RSA. These studies have modelled and estimated that a large amount of movement is available at the glenohumeral articulation, when using a standard glenosphere, with even more movement using an eccentric or large glenosphere. However, the in vivo kinematics of the RSA has not been determined. Therefore, we conducted a study to assess the in vivo kinematics of the RSA and to observe what affect the glenosphere type would have. Areas of specific interest were the maximal abduction, the ratio of glenohumeral to scapulothoracic motion, and an observation of what occurs during notching. We obtained 18 patients who had high functioning reverse shoulder replacements, with surgery greater than a year ago. We assessed the kinematics, first with fluoroscopy, where we obtained 5 images at various levels of abduction. Then, at the same sitting, electromagnetic sensors were placed on the lateral epicondyle, acromion and base of the scapular spine. These sensors were attached to the Polhemus 3space tracking system that allowed us to measure the movement of the humerus and the movement of scapula during cycles of abduction. Our results demonstrated that the RSA is able to reproduce kinematics similar to the quoted physiological kinematics. Eccentric glenospheres had higher abduction and are less likely to experience superior impingement of the humerus on the under surface of the acromion or develop the more severe stages of notching. The range of movement in our study was highest in the 36-mm eccentric glenospheres and lowest in the 44-mm concentric glenospheres. Notching, although not associated with a poor outcome score or a lower range of movement was more prevalent in patients whose first phase of movement, consisted mainly of scapulothoracic motion.

Keywords In vivo kinematics · SMR reverse prosthesis

Study was performed, after approval from both our institution and the regional ethics committee, at North Shore Hospital, Takapuna, North Shore City 0740, New Zealand.

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Introduction

The reverse shoulder arthroplasty (RSA) is a surgical solution for arthritis of the shoulder joint, in association with a deficient rotator cuff. Several studies have demonstrated that it can provide patients, with the appropriate pathology, a good functional improvement [1–3].

Currently, there have been several retrospective evaluations of the survivorship and success of the RSA. There have also been a few in vitro biomechanical studies evaluating the RSA. One of these studies showed that eccentric and larger glenospheres have a greater glenohumeral range of motion [4]. With regards to the evaluation of how the RSA functions in vivo, there has been one published kinematic study, and this used electromagnetic equipment to evaluate the reverse shoulder performing active versus passive movements [5]. This study found that the mean overall glenohumeral to scapulothoracic ratio, for the RSA during abduction, was 1.6 (±0.4) and that there was a statistically significant difference between active and passive abduction.

We set out to assess how the in vivo kinematics of the RSA change, with glenosphere shape, and to examine for a

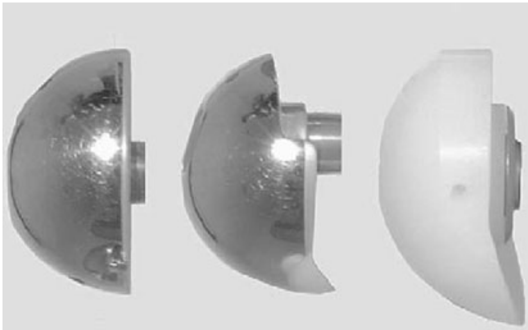

Fig. 1 Different designs of glenospheres used: from *left* to *right* 36-mm concentric, 36-mm eccentric, 44-mm polyethylene concentric glenosphere

kinematic pattern associated with notching. We hypothesised that when eccentric glenospheres were used, there would be a greater amount of abduction and less notching would be found. With regards to notching, we felt it unlikely that there would be a kinematic finding that would result in notching, more that it would be related to mechanical impingement.

Materials and methods

Following ethics approval,[1] we searched the orthopaedic department database, for patients with a well-functioning RSA. The database had serial Oxford shoulder scores, for all patients that had RSAs implanted at our institution. All patients, with Oxford scores of good or excellent, were asked via telephone if they would take part in the study. Eighteen patients agreed to take part; 2 patients had rheumatoid arthritis (RA), whilst the remaining 16 had cuff tear arthropathy (CTA). Patients were an average of 27.6 m from surgery (range: 14–41 m). All patients had a SMR (Lima-LTO Italy) reverse shoulders implanted, with 11 patients having an eccentric glenosphere and the remaining 7 having concentric glenospheres. Out of the groups, there were only two 44-mm glenospheres and they were both in the concentric group (Fig. 1).

With regards to demographics, three patients were male and the remainder were female. The average age of the patient group was 77.3 (62–91), and BMI was 30.1 (21–44).

On the study day, the patients started by completing an Oxford Shoulder score. Then, the investigation commenced with a fluoroscopic (FL) assessment of the RSA. The patient was seated on a chair with their shoulder positioned to ensure the glenosphere baseplate was tangential in all images. Five static images were taken, starting at rest then in full abduction and followed by three further images. The images were made equally spaced by taking a goniometer reading of their maximal abduction and dividing it by four, then with goniometer guidance positioning the patients arm at the appropriate level of abduction. The shoulders were guided to abduct in the plane of the scapula, as the vertical backrest of the fluoroscopy unit was in the plane of the scapula and the patients were instructed to run their arm up it (Fig. 2). The thumb was to be pointed to the ceiling to ensure the rotation profile of the humerus was similar for all patients. The final part to our standardisation was that we placed a foam neck restraint to reduce spine and body movements.

Fig. 2 The standardised fluoroscopic set-up

The images were assessed using AFGA1000 PACS software, and two measurements were taken. The first was the angle of the humerus relative to the body at rest, the position of the humerus was considered the total abduction of the shoulder girdle, and the second was the change in the inclination of the inferior screw, which was considered to be an accurate measure of scapular rotation and thus scapulothoracic (ST) abduction. With this information, we could calculate the glenohumeral (GH) abduction, the total GH/ST ratio and the GH/ST ratios for four phases of abduction. Being able to assess the abduction in four phases resulted in an appreciation of the rhythm of abduction. When evaluating the images, we also looked for impingement inferiorly or superiorly.

The next stage of the study was an electromagnetic (EM) assessment. We used the '3space' system made by Polehemus Vermont, and three electromagnetic sensors were attached. One was attached to the base of the scapular

[1] Ethics approval by Northern Y Regional Ethics Committee, Hamilton, N.Z. Jan 2011.

Fig. 3 The standardised electromagnetic set-up without the neck support on the right

spine, one to the acromion and another to the lateral epicondyle of the humerus. Then, the patients, with the neck immobiliser in situ, were asked to maximally abduct their arm in the same manner (in the plane of the scapula) back to rest five times at their own pace (Fig. 3).

The data were processed so as to calculate the maximal abduction of the shoulder, the overall GH/ST ratio and the GH/ST ratios for each phase of abduction.

Statistical analysis

Spearman's correlation coefficients were used to assess the associations between Oxford scores and the two forms of assessments. The comparisons between the concentric and the eccentric glenospheres were undertaken using independent *t*-tests. A two-tailed P value <0.05 was taken to indicate statistical significance.

Results

Oxford scores

The mean Oxford score for the group was 40.5 (range 3–48); the only significant correlation was those patients with higher abduction, measured electromagnetically, were associated with higher Oxford scores ($r_s = 0.52$, $P = 0.015$).

Maximum abduction

When we compared maximum abduction, the eccentric group had higher values for both fluoroscopic and electromagnetic assessments. However, these differences did not reach statistical significance with a $P = 0.38$ for the fluoroscopic method and a $P = 0.55$ for the electromagnetic method. Fluoroscopically, the mean maximum abduction

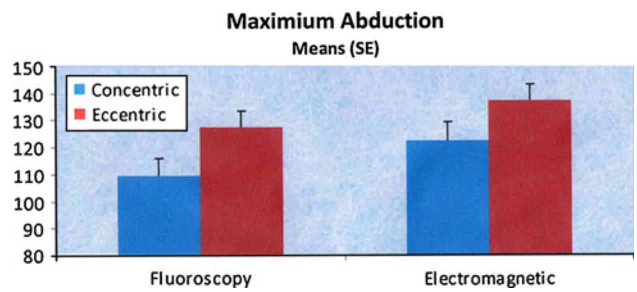

Fig. 4 Mean maximal abduction

for eccentric glenospheres was 127.5° (range 100–169) and for the concentric 119° (115–128) (Fig. 4). Electromagnetically, the mean maximum abduction for eccentric glenospheres was 137 (range 110–164) and for the concentric 131 (100–150).

Rhythm

The total GH/ST ratios were not significantly different between glenosphere shape or size. The mean ratio was 1.3 (0.3–4.8) for the fluoroscopic method and 2.4 (0.4–4.3) for the electromagnetic method (Table 1). Abduction, when divided into 4 levels, demonstrated a larger variability within the first 25% of abduction but with a mean ratio of 7.4, thus motion was predominately glenohumeral. The next phase of abduction, with a mean ratio of 1.6 fluoroscopically (EM-3.2), had a reduction in GH movement so every 1.6° of GH motion resulted in 1 degree of ST. During the third phase, the ratio rose to 3.4 fluoroscopically (EM-4.1), but this increase in relative GH motion was transient as during the fourth phase the mean dropped to 1.8 fluoroscopically (EM-5.8).

There was no difference in rhythm between the glenosphere types.

Table 1 Table of results

	Total (GH/ST)	0–25% (GH/ST)	25–50% (GH/ST)	50–75% (GH/ST)	75–100% (GH/ST)
Fluoroscopic	1.3 (0.3–4.8)	7.4 (0.01–49)	1.6 (0.04–15)	3.4 (0.14–21)	1.8 (0.03–8)
Electromagnetic	2.4 (0.4–4.3)	4.9 (0.1–49)	3.2 (1–7.5)	4.1 (0.9–21)	5.8 (0.3–40)
Normal Inman Freedman	2:1 1.45:1	Setting 1.51:1	Setting 1.51:1	2:1 1.25:1	2:1 1.51:1
Total shoulder Braman Friedman	Pre/post 0.5/1.9 0.5/0.8				

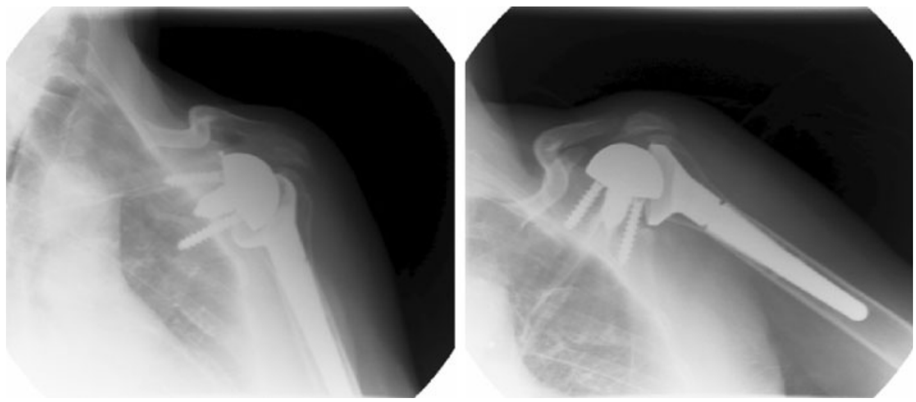

Fig. 5 Grade 2 notch

Notching

Out of the 18 patients, 2 had evidence of notching, using the Nerot grading: there was one grade 1 and the other was a grade 2 (Fig. 5). The grade 2 was present with a concentric glenosphere, whilst the grade 1 was in an eccentric glenosphere. The patient with the grade 1 notch had an abduction of 109° and an Oxford score of 48, whilst the grade 2 patient had maximum abduction 115° and an Oxford score of 46. Both cases had little glenohumeral motion in the first phase of abduction, with GH/ST ratios of <0.1.

Superior impingement

There were two types of superior impingement, one was with the humeral component impinging on the glenoid and this was found with an eccentric implant (Fig. 6a). The other type of impingement was of the proximal humerus on the underside of the acromion, which was found with a concentric component (Fig. 6b).

Discussion

Our main aim was to assess the in vivo kinematics of the RSA and observe how it varies with glenosphere shape and size. As stated in the introduction, currently, there has been only one kinematic study of the RSA, whose main finding was the RSA has higher levels of abduction with passive movement than with active [5]. Their mean active abduction was 80°, and they had a total GH/ST ratio of 1.6. Other biomechanical studies have demonstrated that eccentric and larger diameter glenospheres increase abduction and range of motion [4]. Our study set out with the belief that like the Jeroen study, there would be less GH/ST motion, than the normal ratio quoted by Inman of 2:1 and that given the evidence of the biomechanical studies, there would be greater movement within the eccentric group. Overall, our results concurred with our hypothesis, despite not reaching statistical significance, our study did observe some interesting findings. First, with regards to the rhythm, we like Inman [6] observed the first phase of abduction had a high variability but was predominantly glenohumeral with an average fluoroscopic ratio of 7.4 and an electromagnetic ratio of 4.9. The data, as Freedman found, had a drop of the glenohumeral motion in the second phase for the electromagnetic assessment and in the third phase for the fluoroscopic assessment, to be subsequently followed by an increase in glenohumeral motion. When comparing the two types of assessment, there was a greater amount of glenohumeral motion with the electromagnetic method. We believe this result is due to the static shots of the fluoroscopic group requiring the shoulder girdle to provide a greater support to

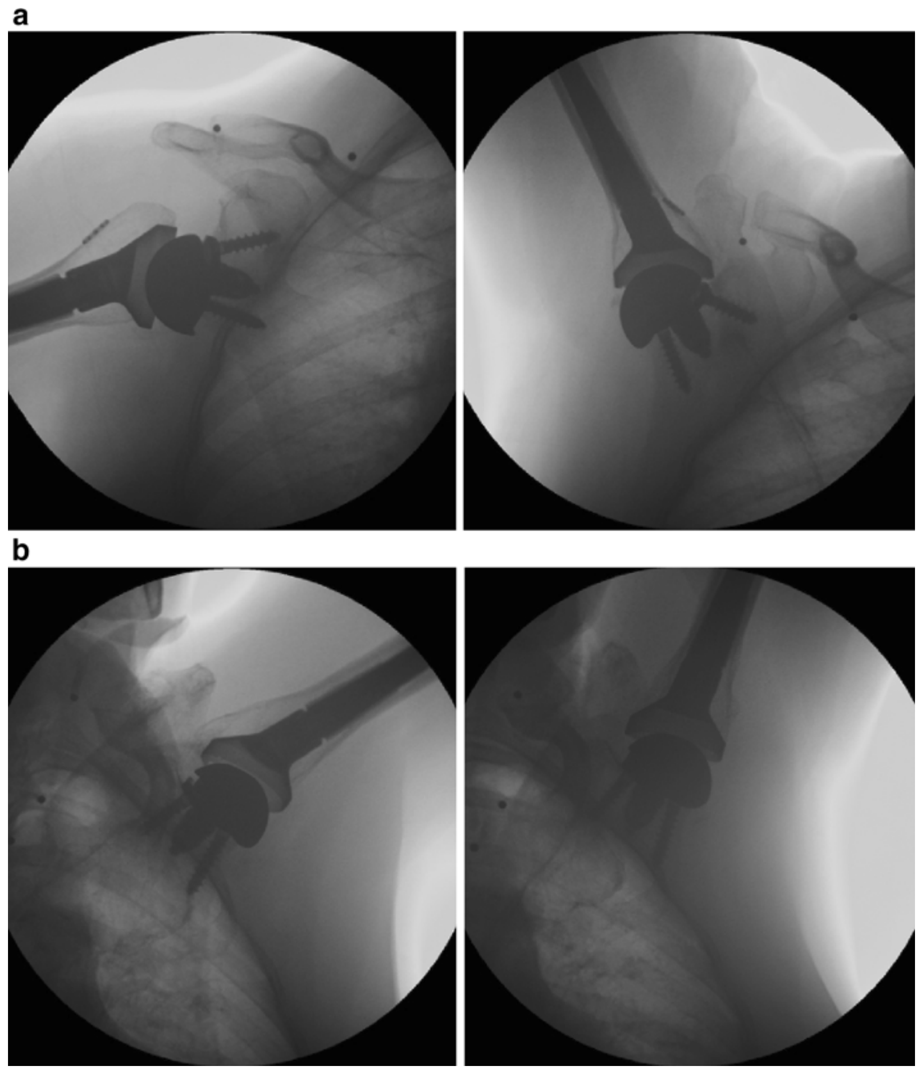

Fig. 6 **a** Eccentric superior impingement. **b** Concentric superior impingement

the arm; as other studies have demonstrated that people with larger arms have lower GH/ST ratios [7]. Although a confounder to this may be that in the case of the RSA, the patients are generally elderly and as such have more mobile skin, rendering the electromagnetic assessment less reliable.

The second interesting area was with regards to impingement and notching. In a large published study of notching, there was a reported association with higher activity levels and in the presence of notching a slight reduction in range of motion and strength [8]. In our group, there were two cases of notching, one grade 1 notch that was present with an eccentric glenosphere and the other a grade 2 notch that was present with a concentric glenosphere. The only association between these was that they both had very low GH motion in the first phase of abduction; this lack of motion can be seen in the fluoroscopic images to result in impingement as the scapula rotates upwards. It may be that the notching was worse in the concentric glenosphere, as the eccentric glenosphere inferiorised the humerus so providing relative protection.

There were also two cases of superior impingement; one was of the humeral component on the glenoid and the other of the proximal humerus on the underside of the acromion. We theorise that the glenosphere type will determine the form of impingement, as demonstrated in the fluoroscopic images, and the eccentric glenosphere with a lower centre of rotation impinges the humeral component on the glenoid. Whilst the concentric glenosphere, with a higher centre of rotation, results in impingement of the humerus on the underside of the acromion. The significance of this is unknown, but both of these patients had high oxford scores and abduction greater than 153°.

The strengths of the study included the selection of high functioning RSAs and observing how their kinematics worked using two methods of assessment, in particular, the fluoroscopic method permitted an evaluation of impingement. Our weaknesses have been mainly with regard to our small numbers. We had two 44-mm concentric glenospheres, five 36-mm concentric glenospheres and eleven 36-mm eccentric glenospheres. Also, our study used the

SMR reverse prosthesis, thus other makes of the RSA with different designs may have different kinematics.

With regards to our methods of assessment, both had potential weaknesses. Fluoroscopic assessment has been seen as unreliable in physiological studies, due to the difficulty of identifying bony landmarks. However, given all images were taken tangential to the base plate of the glenosphere, a change in the inclination of the scapular screws may be seen as a reliable assessment of scapulothoracic upward rotation, and elevation of the humeral stem may be viewed as a reliable method of total abduction. Also, the electromagnetic method, which is the most common method of measurement used in kinematic studies, does have a small amount of variation due to skin motion artefact. This artefact is unavoidable unless trans-cortical pins are used, which in themselves creates two other problems, first movement maybe altered due to discomfort and second the recruitment of patients may become more difficult.

In conclusion, based on the data from biomechanical studies and the data from our study, eccentric glenospheres are likely to provide better abduction and less inferior impingement. Indeed, following another study performed at our institution that demonstrated eccentric glenospheres had increased micromotion but were well within the accepted limits for osseous ingrowth [9], we have moved to using eccentric glenospheres as our implant of choice. However, in order to assess whether the trends observed in our study are statistical significant, a further study with larger numbers is required.

The additional value we see in our study is that it commences the investigation into the in vivo kinematics of the RSA, an area that has been under evaluated. With future exploration of the motion and limitations of the RSA, the knowledge obtained may aid future implant design and surgical technique.

In summary, the RSA can reproduce kinematics similar to the quoted physiological kinematics. Eccentric glenospheres have a trend towards higher abduction and appear less likely to experience superior impingement of the humerus on the under surface of the acromion or develop the more severe stages of notching. Currently, our study provides some more information on the topic of 'the in vivo kinematics of the reverse shoulder arthroplasty.'

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Conflict of interest None.

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