



The effect of component positioning on intrinsic stability of the reverse shoulder arthroplasty

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Hypothesis: Anterior instability is one of the most common complications in reverse shoulder replacement. This study hypothesized that intrinsic stability of a reverse prosthesis varies with the degree of version of the humerus and glenoid components. This should provide guidelines on how to best position the implant components to decrease the rate of dislocation.

Materials and methods: Resistance to anterior dislocation of a reverse implant was measured in a mechanical testing machine by means of the stability ratio (ratio of peak dislocation/axial compressive forces). Versions of the humeral and glenoid components were modified in 10° steps in the 90° abducted and resting positions.

Results: In both tested positions, the effect of humeral component version was highly significant. Only a glenoid component retroversion of 20° led to a statistically significant drop in stability ratio for the 20° abducted position. Intrinsic stability in the typical component positioning (neutral glenoid version and 20° humeral retroversion) yielded comparably low intrinsic stability, which could only be improved by increasing anteversion of the humeral component.

Discussion: Version of the humeral component is the critical factor for intrinsic stability. Version of the glenoid component is less important for intrinsic stability, but special care should be given to avoid retroversions of more than 10°. Within this range, the surgeon can concentrate primarily on other parameters critical for long-term outcome (range of motion, secure fixation) when choosing the appropriate glenoid version.

Conclusion: Anterior stability can be improved by implanting the humeral component in neutral or with some anteversion.

Level of evidence: Basic Science Study, Biomechanical Study

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Keywords: Reverse shoulder; delta prosthesis; intrinsic stability; dislocation; instability; glenoid version; humeral version; component positioning

In cuff tear arthroplasty,²⁹ the reverse prosthesis has been recognized as an adequate treatment to relieve pain and restore function.^{37,41} In the absence of active stabilization by the rotator cuff muscles, joint stability is achieved passively

by replacing the articular surface with a semiconstrained prosthesis offering increased intrinsic stability.²³ However, instability still remains a common complication in reverse shoulder arthroplasty.^{6,10,13,14,23,27,37,40} Dislocation was reported to occur exclusively in the anterior direction.^{27,34} Instability was identified as the most frequent complication, with an incidence of 7.5% after a 39.9-month mean follow-up,⁴¹ and could even be observed in 20% of patients at a 1-year follow-up.³⁴

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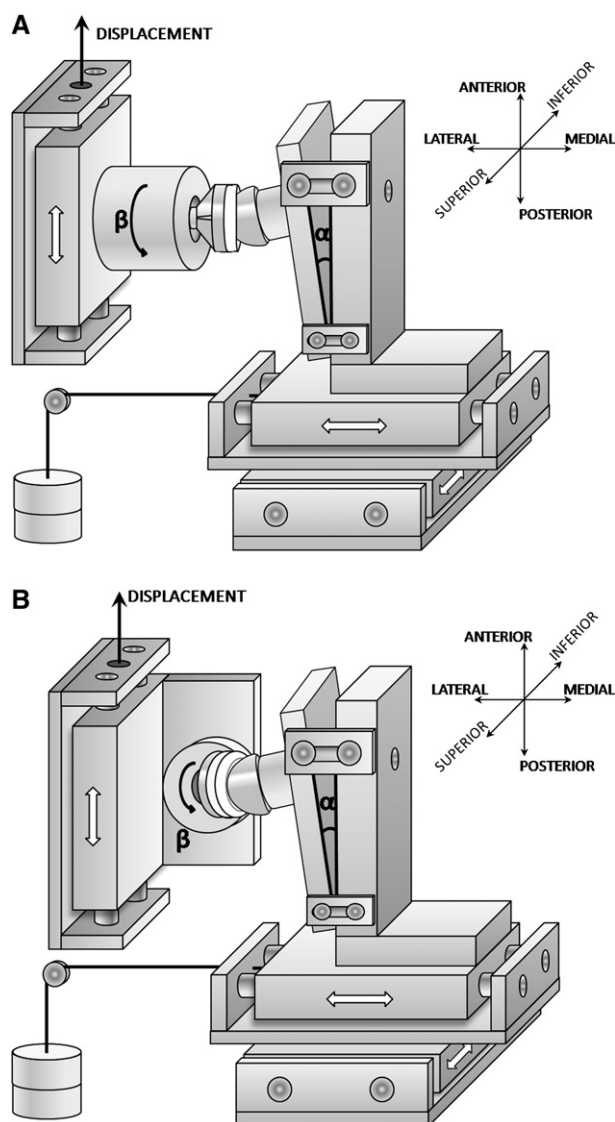


Figure 1 Schematic of the test setup for the (A) 90° and (B) resting positions. A constant compressive load of 40 N was applied from medial to lateral by means of weights and pulley. A constant displacement of 10 mm/s was imposed to the humeral part from posterior to anterior until dislocation. The glenoid component was allowed to translate in the medial to lateral and inferior to superior directions. The clamps allowed adjusting the versions of the glenoid (α) and humeral (β) components individually.

This high rate of dislocation and the current lack of knowledge about possible causes call for a better understanding of the factors involved in instability.^{7,17} Distortion of the osseous and soft-tissue anatomy by prior trauma, poor deltoid tensioning, inappropriate ratio between the central depth and the diameter of the concave component, leverage of the humeral component against the glenoid bone, and malpositioning of components have been identified as possible causes of instability.^{4,13,17,23,25,35,40} Revision surgery for correction of instability has been advocated for component malpositioning.²³ However until

now, no clear and explicit recommendations for adequate component positioning have been available.²⁰

A primary factor in resisting dislocating forces is the geometry (conformity and constraint) of the implant itself,^{2,11,32,36} especially in the semiconstrained reverse setting.^{4,5,13,17} Within a defined design, however, the stability depends on relative positioning of the components, a factor that is directly controllable by the surgeon during implantation. Our hypothesis is that intrinsic stability of a reverse prosthesis varies with the degree of version of the humerus and glenoid components. This should provide guidelines for the surgeon on how to best position the implant components to prevent reverse joint instability.

Materials and methods

Investigational Review Board approval was not required for this study.

Resistance to dislocation or intrinsic stability of an implant can be measured with the stability ratio, defined as the ratio of the peak dislocation force to a given axial compressive load.^{2,11,18,26,31,38} For the current study, testing of intrinsic stability for the reverse shoulder prosthesis was adapted from the method used in conventional shoulder arthroplasty (Fig. 1).^{2,11,38} Glenoid and humeral components of a size 36 Delta III total reverse shoulder prosthesis (DePuy Inc, Warsaw, IN) were rigidly fixed in specially designed clamps to allow for independent adjustment of both component versions. The glenosphere was fixed on 2 linear tables (SFERAX SA, Cortaillod, Switzerland) mounted perpendicularly, to simulate the 2 translational degrees of freedom of the shoulder joint along the inferior to superior and medial to lateral directions.

A constant compressive load of 40 N was applied from medial to lateral by means of a weight and pulley attached to the corresponding linear table. This load was chosen to comply with previous investigations.^{18,26,30,38} The starting position was defined as the fully centered position. Because the glenoid component could translate freely in the inferior to superior and medial to lateral directions, the components were automatically brought in a centered position along these directions by the compressive load. To center the components in the anterior to posterior position, a minimum load was searched with the testing machine (Universal Testing Instrument, model 4204, Instron Corp, Canton, MA).¹⁸ From this starting position, a constant displacement of 10 mm/s was imposed to the humeral component, and the load-displacement curve was recorded until dislocation. With anterior instability being the exclusive reported direction of dislocation in the reverse setting,^{27,34} the dislocation force was applied from posterior to anterior through the vertical actuator of the testing machine. However, by virtue of symmetry of both the glenoid and humeral components in the anterior to posterior direction, results for anterior dislocation mirror the behavior of the system in the posterior dislocation.

Two important positions of arm elevation were considered (Fig. 1 and Fig. 2). The 2 prosthetic components were placed in about 60° of relative glenohumeral abduction, corresponding to approximately 90° of humeral abduction relative to the torso.²² In this position, the back surface of the components are parallel when

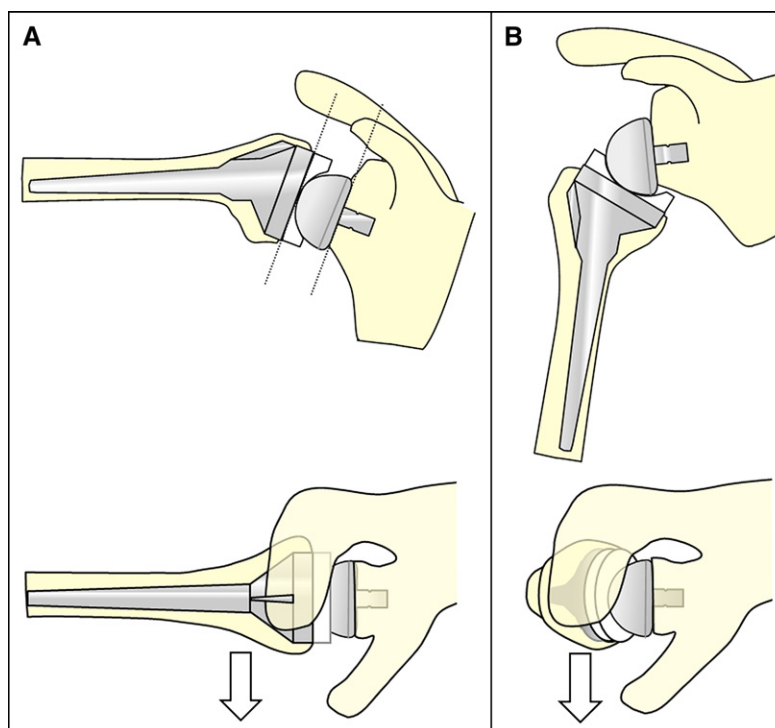


Figure 2 The arm was tested in 2 positions. The top drawings represent an anterior view, and the bottom drawings show a cranial view, matching with the corresponding drawing of the set up in Fig. 1. (A) In the position corresponding to 90° humerothoracic elevation, the back surfaces of the 2 components are parallel to each other (*dashed lines*). (B) Arm in the resting position.

both components are in neutral version (Fig. 2, A). This configuration was chosen because the coverage of the articular contact surfaces is maximal so that the greatest stability ratio was expected. Also, a position of 20° abduction was tested to simulate the hanging-arm or resting position (Fig. 2, B).²⁴ This position was chosen because the coverage of the articular contact surfaces was less than in the 90° abducted position so that a lower stability ratio was expected.

For both arm positions, version of the glenosphere was successively set from 20° retroversion to 20° anteversion in 10° steps. Respectively for each of these glenosphere versions, the humeral component version was set to neutral, 10°, and 20° retroversion and anteversion. Three measurement repetitions in each configuration were performed, with standard deviations typically less than 5% of mean measured values. This study therefore totaled 150 trials.

The stability ratio was finally calculated as the force at dislocation (corresponding to the peak force in the load-displacement curve) divided by the constant compressive load of 40 N.¹¹

Statistical analysis was performed with a one-way analysis of variance to test the influence of the humeral and glenoid component versions. When significant differences were obtained, a post hoc test with Bonferroni correction was added. The level of significance was set to $P < .05$.

Results

The stability ratios measured during anterior dislocation for the 90° abduction and the resting positions, in the full tested

range of glenoid and humeral component versions, are shown in Fig. 3, A and B, respectively. The glenosphere version is varied along the horizontal axis of the graph, and the stability ratio is displayed on the vertical axis. A different marker type is plotted for each tested angle of humeral component version. In both graphs, the standard implant configuration with the glenoid in neutral version and the humeral component in the physiologic 20° retroversion is encircled.

In 90° of abduction, no significant influence of the glenosphere version was detected ($P = .97$), but the effect of humeral component version was highly significant ($P < .001$). On average, a change of 10° in humeral component version affected the stability ratio by 21%, whereas an identical alteration in glenoid component version induced a change of the stability ratio of 5%. The standard implant configuration yielded the second worst stability ratio of all tested configurations and could only be increased by anteverting the humeral component.

Significant differences in the stability ratio in the resting arm position were also reached for all changes in versions of the humeral component ($P < .002$). For the version of the glenosphere, significant differences were reached when the data of 20° glenoid retroversion were compared with 10° glenoid retroversion ($P < .01$) and with the neutral glenosphere version ($P < .005$). On average, a change of 10° in humeral or glenoid component version affected the stability ratio by 27%, respectively, 15%. Compared with

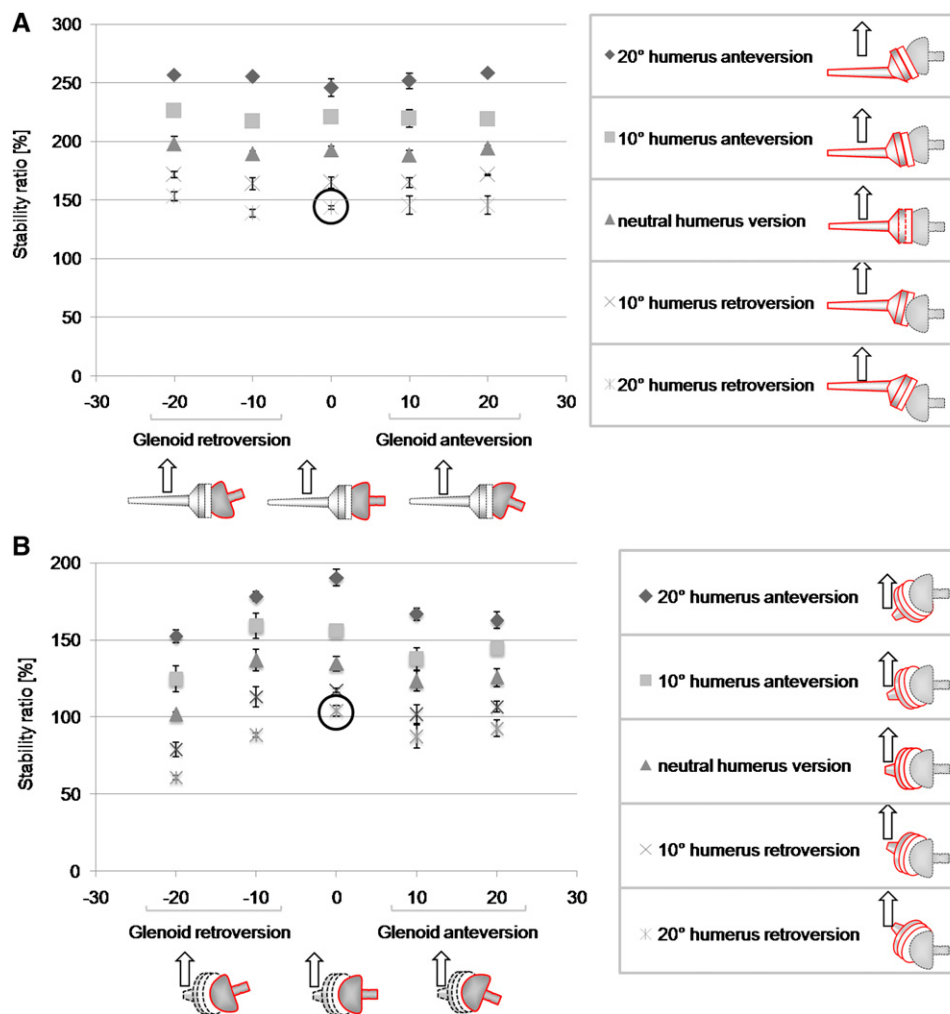


Figure 3 Stability ratios (vertical axis) for (A) the 90° abduction and (B) the resting positions, for the full range of tested glenoid (horizontal axis) and humeral (different points series) component versions. The small drawings represent a cranial view of the testing configuration. Only the dislocating force is drawn (arrow). The compressive component is not shown but was present in all cases, pressing the glenoid against the humeral component. The encircled data point represents the standard configuration with the glenoid in neutral version and humeral component in 20° retroversion.

the standard implant configuration, the stability ratio could only be increased by anteverting the humeral component but could be reduced by retroverting the glenoid component.

The stability ratio was higher in the 90° abducted position than for the corresponding configurations in the resting position. When both components were in neutral position, the stability ratio was 193% in 90° of arm abduction and 135% for the resting arm position.

Discussion

The high rate of dislocation observed in reverse shoulder replacement^{23,27,34,40,41} calls for a better understanding of the features involved in stability.^{7,17} Intrinsic stability of the semiconstrained reverse prosthesis plays a dominant role to

maintain a stable joint because of the mostly deficient active muscular stabilizers.^{4,13} This study tested the hypothesis that intrinsic stability of a reverse prosthesis varies with the degree of version of the humerus and glenoid components.

Glenoid component version was shown to have generally less influence on intrinsic stability of the reverse total shoulder than the humeral component. The glenosphere articular contact surface is spherical, so a change in version is similar to revolving a ball about its center, which does not affect the incidence angle, defined as the angle between the glenosphere and the humeral socket edge.^{2,17}

For the resting arm position with the glenosphere in 20° retroversion, however, a statistically significant drop in the stability ratio was measured for all humeral versions. In this particular configuration, the hole on the surface of the glenoid component for the central screw that fixes the

glenosphere to the base plate is very close to the border of the polyethylene cup and may affect the contacts between the 2 components. The clinical consequence is that positioning of the glenosphere can be focused on optimizing fixation by maximizing screw length, accomplishing far cortical fixation, attaining screw purchase in good bone stock and avoiding undesirable tensile forces on the metaglene/baseplate interface and screws^{16,19} without regards to the future joint stability. This is especially helpful in case of poor glenoid bone stock, where the version of the glenosphere can be slightly adapted from 10° retroversion to 20° anteversion to profit from the best bone available. However, special care should be taken to avoid glenoid retroversions of more than 10° because this led to a drop in intrinsic stability in the resting position. Therefore, in the presence of posterior glenoid bone deficiency of more than 10°, glenosphere version should be restored for stability.

Our results indicate that, within a defined implant design, 2 main parameters affect the intrinsic stability of the reverse prosthesis:

First, the humeral component version has a significant influence. These results are in complete opposition to what has been shown in conventional arthroplasty.³⁸ To generalize for all shoulder replacement types, we can state that intrinsic stability is essentially determined by the spatial position of the concave components, which are the glenoid in a conventional and the humerus in a reverse total shoulder. Therefore, increasing retroversion of the reverse humeral component in the hope of improving external rotation would affect not only internal rotation⁵ but also joint stability. A transfer of the latissimus dorsi combined with the reverse shoulder replacement might be preferable to improve external rotation.^{8,12}

Second, intrinsic stability is influenced by the degree of abduction. In the intact joint, the stability ratio decreases slightly with glenohumeral abduction, with a maximum in the resting position.¹⁸ This was identified as a physiologically advantageous situation, allowing the stabilizing muscles to be more relaxed in the resting position. In the reverse prosthesis, an opposite trend is observed, with a stability ratio that averages 60% higher in the 90° abducted position than in the resting position. This is potentially associated with decoaptation through impingement of the humeral component on the glenoid/scapular neck,⁴ which may partly explain why the reversed shoulder dislocates in the adducted position³⁵ whereas the intact joint is likely to dislocate in the abducted and externally rotated position.⁴²

The standard configuration (encircled data in Fig. 3 with the glenoid in neutral version and the humeral component in the physiologic 20° of retroversion) yielded low intrinsic stability. In the 90° abducted position, this was even the second worst scenario. Compared with this standard configuration, intrinsic stability of the implant can only be improved by increasing the anteversion of the humeral component, yielding a gain of more than 20% stability for each 10° of anteversion. A multicenter study²⁷ showed that

a minimal retroversion or some anteversion led to far more favorable clinical results. Furthermore, anteversion of the humeral component was associated with an increase in radiologically measured passive internal rotation with the arm adducted but with no significant influence on the degree of passive and active external rotation.²⁰

Our data show that the reported favorable clinical outcomes associated with anteversion of the humeral component would also be accompanied by an increase in anterior intrinsic stability. Excessive humeral component anteversion should be avoided, however, because this may limit external rotation in other positions than the previously reported adducted arm position.²⁰ In addition, by virtue of the system symmetry, excessive anteversion would lead to a decrease in the stability ratio in the posterior direction, which may potentially lead to posterior instability.

With the humerus in 90° of abduction and neutral axial rotation, the *in vitro* stability ratio of the shoulder (with all soft tissues removed, but with an intact labrum) reached 30.4% in the anterior direction and 36.6% in the posterior direction, with an average compressive load of 40 N.¹⁸ Values for conventional total shoulder prostheses ranged from 51 to 85 with a 44 N compressive load, depending on the tested model.¹¹ In the reverse prosthesis, we measured values that were more than 5 times higher than those in the normal joint and 2 to 3 times higher than those in conventional shoulder prostheses, confirming recently published values.¹⁷ This greater intrinsic stability allows the shoulder implanted with a reverse prosthesis to be less dependent on a functioning rotator cuff for joint stability.^{4,13}

Simplifications were made in this study. One design of reverse prosthesis was used. Glenohumeral size has a negligible effect in intrinsic stability, whereas socket depth is important.¹⁷ Within a given implant design, however, the conclusions drawn on the influence of component positioning can be generalized to any reverse shoulder implant. The magnitude of the load applied to the joint was not representative of the forces acting *in vivo*.^{3,9,21,33,39} Because the *in vivo* forces causing dislocation of the reverse prosthesis remain unknown,¹⁷ this force was selected to reproduce the standards implemented in previous studies^{18,26,31,38} and was chosen low enough to avoid deformation of the polyethylene cup.^{1,11} Furthermore, a linear relationship has been shown between the compressive and the dislocation force,¹⁷ indicating that the stability ratio is independent of the compressive load in the reverse setting. The influence of the soft tissues was not modelled because of the technical difficulty associated with changing the version of the glenoid component by reimplantation.³⁸ As in previous studies,^{11,17,26,28,36} intrinsic stability of the articulating surface was therefore assessed alone to isolate the influence of the components version only, eliminating bias from other factors such as distortion of soft tissues by prior trauma, deltoid tensioning, and decoaptation. The stabilizing or destabilizing effect of the

muscles, ligaments, and capsule can be considered to be integrated in the resultant force applied to the joint.² Conversely, the influence of component positioning on soft tissue tension,⁷ range of motion,^{15,30} eccentric loading, and loosening require further investigations.

Conclusions

The relationship between component positioning and intrinsic stability of the reverse shoulder has been quantified. Intrinsic stability of an inverse total shoulder implant of a given geometry depends essentially on humeral component version. To improve intrinsic stability, the humeral component can be positioned in neutral version or slight anteversion. The less important effect of glenoid component version on intrinsic stability gives more range in positioning the glenoid component for focussing primarily on fixation or range of motion while avoiding retroversions of more than 10°. This is especially helpful in case of poor glenoid bone stock, where the version of the glenosphere can be slightly adapted to profit from the best bone available.

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Disclaimer

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