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Lateralization in reverse shoulder arthroplasty: A review

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ABSTRACT

Reverse shoulder arthroplasty, as originally designed by Grammont, has revolutionized the treatment of rotator cuff arthropathy as well as fractures about the proximal humerus. The original design consisted of glenoid and humeral components with a medialized center or rotation compared to the native shoulder. Long term outcome studies on this design demonstrated high rates of scapular notching as well as significant loss of external rotation. To combat these flaws, prosthesis design has evolved to include the concept of lateralization whereby the center of rotation is moved laterally compared to the Grammont prosthesis via either the glenoid or humeral components. Lateralization via the glenoid component has sought to reduce scapular notching, however, concerns over early loosening have been raised secondary to increasing stress at the glenosphere/glenoid interface. Lateralization via the humeral component has been theorized to improve the mechanics of the remaining rotator cuff and deltoid musculature while avoiding the problems inherent with glenoid lateralization. While limited clinical evidence is available currently to support one design over the other, multiple biomechanical studies have shown improvements in rates of scapular notching and post-operative external rotation for lateralized humeral and glenoid components. Future research should aim to delineate advantages of one design over the other or optimal combinations of the two designs.

1. Introduction

Reverse total shoulder arthroplasty (RTSA) has become one of the most common procedures performed on the shoulder. RTSA is commonly used in both primary and revision settings. Over 4000 reverse shoulder arthroplasties were performed in Great Britain alone in 2012 accounting for over 30% of all shoulder arthroplasties and RTSA has come to account for 52% of shoulder arthroplasties performed in the United States.[1] While originally designed for treatment of rotator cuff arthropathy, RTSA indications have greatly expanded to include treatment of fractures, severe bone loss, revision arthroplasty, and salvage procedures. Just as the indications for RTSA have changed, so too has the design of the prosthesis. The original Grammont prosthesis utilized a center of rotation placed directly at the glenoid/glenosphere interface to avoid torque, subsequent micromotion, and promote prosthesis ingrowth. Despite excellent outcomes and longevity with the Grammont prosthesis, several consistent flaws have demonstrated and redemonstrated themselves in the literature including scapular notching, loss of external rotation, and instability. The concept of lateralization was developed to combat these inherent disadvantages with a medialized glenoid design in the original Grammont prosthesis. The purpose of this review article is highlight the different methods of lateralization as well as the biomechanical and clinical implications in reverse total shoulder arthroplasty.

1.1. Biologic lateralization

Biologic reverse shoulder arthroplasty (BIO-RSA) was initially developed to combat posterior glenoid bone deficiencies frequently encountered during shoulder arthroplasty. Failure to correct these deficiencies at the time of surgery can lead to excessive glenoid component retroversion, thereby decreasing external rotation, increasing posterior scapular notching, and increased posteromedial polyethylene wear.[2,3] Additionally, as posterior bone loss increases, correction with eccentric reaming will lead to greater glenoid prosthesis medialization, thereby decreasing flexion strength, deltoid wrapping, and increasing the likelihood of instability.[4]

Boileau et al. initially developed the BIO-RSA technique to combat the inherent drawbacks of the medialized prosthesis while maintaining the advantages of a medialized center of rotation. In this technique, a disk of cancellous bone is secured between the native glenoid surface and a modified glenosphere baseplate. By doing so, the glenoid center of rotation is placed at the bone graft/glenosphere interface, thus reducing the amount of torque experienced by the glenosphere once the

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graft has healed.[5] The authors reported excellent results, with a 98% healing rate of the autograft, no glenoid component loosening at 28 months, and 93% of patients reporting satisfying or very satisfying results. Rates of scapular notching were also significantly decreased to 19% compared to the original Grammont prosthesis at 74%.[5]

One potential drawback of the BIO-RSA technique is a higher rate of post operative scapular stress fracture. Kirzner et al. reported a 16.7% rate of post operative scapular stress fracture with BIO RSA compared to 9.1% rate in standard reverse shoulder athroplasty.[6] Those with scapular fractures had significantly lower ASES and WOOS scores. The authors cited osteoporosis as a major risk factor for fracture in their series.

1.2. Lateralization through prosthesis design

Various prosthetic designs have been formulated in order to improve outcomes and longevity after RTSA. In an attempt to organize these developments, Routman et al.[7] proposed a classification for prosthesis design based on prosthesis characteristics that alter its biomechanical properties. Under this classification system, a glenoid prosthesis is termed medialized if the center of rotation is $<$ 5 mm from the glenoid face and lateralized if it is $>$ 5 mm from the face. The humeral component is classified based on the horizontal distance from the center of the intramedullary canal to the center of the humeral liner. The humeral component is deemed medialized if this distance is $<$ 15 mm and lateralized if it is $>$ 15 mm. Humeral lateralization is influenced by humeral neck angle, humeral head osteotomy, and use of an inset or onset humeral tray.

1.3. Lateralized glenoid, medialized humerus

Lateralized glenoid components achieve lateralization by thickening the glenosphere to values greater than its spherical radius thus moving the center of rotation lateral to the baseplate/glenoid interface. They are typically combined with a medialized or inset humeral prosthesis and are termed lateralized glenoid, medialized humerus (LGMH)[7] (Insert Fig. 1). The lateralized center of rotation design is theorized to restore more native tension on the remaining rotator cuff musculature, thus improving rotation range of motion compared to medialized COR designs.[8]

1.4. Medialized glenoid, lateralized humerus

Prostheses with lateralized humeral components and medialized glenospheres have an onset humeral stem design that when placed on top of an anatomic humeral neck osteotomy allows for lateral displacement of the humerus (Insert Fig. 2). This produces better tensioning of the anterior and posterior rotator cuff and also lengthens the deltoid moment arm thereby improving its efficiency.[9] The MG/LH prostheses allow for decreased torque at the glenosphere/glenoid interface associated with a medialized glenoid while still producing tension on the residual rotator cuff, improving deltoid wrap, and increasing the deltoid abduction moment arm.[7] Lower neck shaft angles in lateralized humeral prostheses have also been associated with lower rates of scapular notching compared to the MGMH design.[10]

1.5. Biomechanical evidence for lateralized prostheses

1.5.1. Effect on initial glenosphere fixation

Lateralization of the center of rotation away from the glenosphere/glenoid interface has the disadvantage of increasing torsional forces at the fixation interface, thus theoretically increasing the risk of mechanical loosening. While an increase in the amount of micromotion has been noted in biomechanical studies, it has not been shown to exceed the maximum amount of micromotion allowed for bony ingrowth until 10–15 mm of glenosphere lateralization was utilized.[11]

In evaluating the effect of glenosphere sided lateralization vs BIO-RSA on glenoid fixation, Denard et al. found that maximum amounts of micromotion for bony ingrowth were exceeded with only 5 mm of bony lateralization, whereas these levels were not achieved until 10–15 mm of glenosphere lateralization.[12]

1.5.2. Effect on scapular notching

Scapular notching is a well-known and well documented complication of reverse total shoulder arthroplasty. The causes of scapular notching are likely multifactorial, with a medialized center of rotation, superior placement and superior tilt of the glenosphere, glenosphere diameter, eccentric glenosphere design, and higher humeral implant neck/shaft angles all implicated in causation. Recent evidence has demonstrated a significant decline in constant scores, active flexion and abduction, and subjective shoulder scores with increasing severity grades.[13] Scapular notching has also been shown to increase micromotion at the baseplate/glenoid interface which may potentiate early aseptic loosening.[14]

The ability of a lateralized prosthesis to reduce the incidence of scapular notching has been demonstrated in the literature several times. In a recent systematic review, Lawrence et al. found the incidence of scapular notching to be 5.4% in 136 lateralized glenoid components

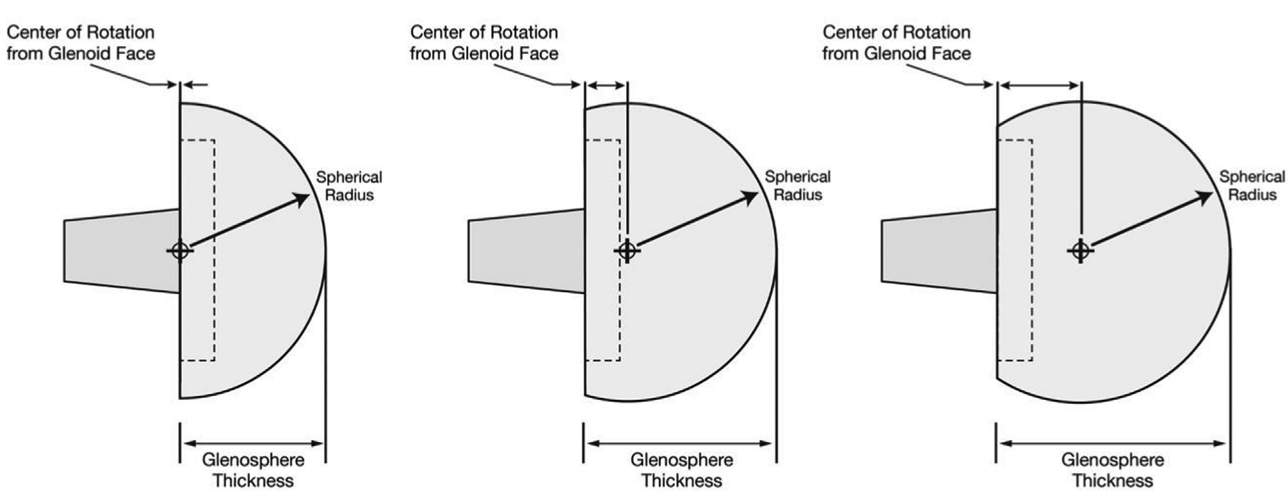

Fig. 1. Graphic demonstrating lateralization of center of rotation as a function of increasing glenosphere thickness (Reprinted from: Routman HD, Flurin PH, Wright TW, Zuckerman JD, Hamilton MA, Roche CP. Reverse shoulder arthroplasty prosthesis design classification system. Bull Hosp Jt Dis. 2015;73(Suppl 1):S5-14. With permission).

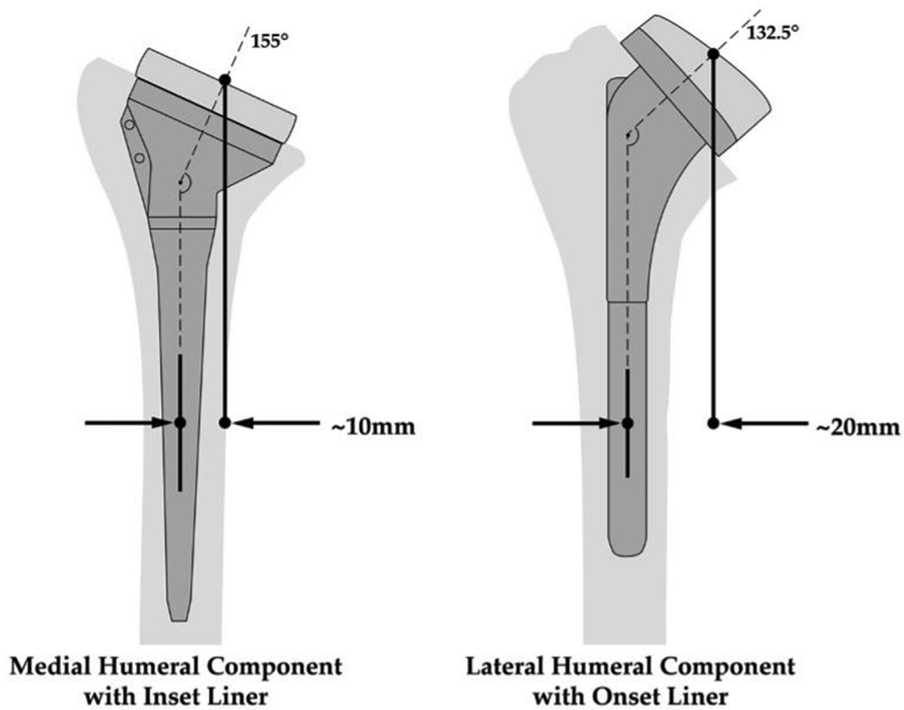

Fig. 2. Demonstration of humeral component lateralization as a function of neck shaft angle and an onset stem design (Reprinted from: Routman HD, Flurin PH, Wright TW, Zuckerman JD, Hamilton MA, Roche CP. Reverse shoulder arthroplasty prosthesis design classification system. Bull Hosp Jt Dis. 2015;73(Suppl 1):S5-14. With permission).

compared to 45% of 213 shoulders who had a more traditional medialized COR glenoid component.[15] Despite the lowered rate of scapular notching, the authors did note a glenoid component loosening with a lateralized component of 8.8% vs 1.8% in the traditional group.

In a review of 140 reverse-TSA's with a lateralized glenoid component, Katz et al. demonstrated a reduction in the rate of scapular notching to 29% at a mean follow up of 45 months, of which 92% were grade I or grade II according to the Sirveaux classification.[16] The authors noted that no patient with grade I or II notching had evolution at further follow up and functional outcomes were not affected. These results should be viewed in conjunction with an earlier study by the same authors in which no notching was noted at a mean follow up of 24 months.[17]

The effects of the humeral lateralization on scapular notching have also been evaluated. In a finite element analysis model of reverse shoulder arthroplasty, decreasing neck shaft angles from 155° to 145° were noted to decrease contact area at the inferior scapular neck by 29% while decreasing the angle from 155 to 135 decreased contact area by 59%.[18] Similarly, adding lower neck/shaft angles in combination with a lateralized glenoid component demonstrated lower clinical rates of scapular notching ranging from 2.83% to 12% compared to the more traditional Grammont style prostheses.[10]

1.5.3. *Effect on deltoid and rotator cuff efficiency*

Lateralization built into RTSA design was also conceptualized to combat rotational deficits seen with the more traditional Grammont prosthesis. Lateralization of the humeral component through lower neck/shaft angles and onlay humeral components provides the benefit of restoring tension in the remaining rotator cuff musculature and may be used in conjunction with a more medialized glenoid component.

Several biomechanical studies have demonstrated improved rotator cuff moment arms with humeral lateralized designs. The moment arms for teres minor, infraspinatus, and posterior deltoid muscles have been show to be largest with a lateralized humeral design compared to MGMH, LGMH, and BIO-RSA designs.[19] This larger moment arm may aid in increasing external rotation compared to other prosthesis designs. Similarly, Chan et al. demonstrated in a cadaver study that increasing humeral component lateralization lead to higher degrees of internal and external rotation with the arm at 0° abduction.[20]

Humeral lateralization has also demonstrated positive effects on deltoid muscle efficiency. In a cadaver study, Giles et al. tested the effects of humeral lateralization, polyethylene insert thickness, and glenosphere lateralization on the efficiency of the deltoid muscle to produce abduction as well as the magnitude of joint load at rest and throughout abduction. Humeral lateralization was noted to be the only parameter to improve deltoid efficiency without increasing joint loading.[21] Notably, this increase in deltoid efficiency was able to offset a portion of the decreased deltoid efficiency seen with a lateralized glenosphere design.

1.5.4. *Effect on joint reactive forces and stability*

The effect of the lateralized design has also been theorized to increased compressive joint reactive forces and thereby enhance stability of the prosthesis. Both the LGMH and MGLH designs significantly increase compressive joint reactive forces in abduction, forward flexion, internal rotation, and external rotation compared to MGMH designs, thereby enhancing joint stability.[22]

To evaluate the effect of lateralization on stability, Ferle et al. implanted LGMH reverse shoulder arthroplasties in 19 cadaveric specimens with 0–9 mm of lateralization in combination with neck shaft angles of 135, 145, and 155°. Anterior stability was checked in 30 and 60° of abduction in combination with neutral and 30° of external rotation. The authors were able to conclude that joint lateralization significantly increased stability while humeral neck-shaft angle had only a small effect on stability with the arm in 30° of abduction and 30 of external rotation.[23]

1.5.5. *Effect on external rotation*

Several clinical studies have demonstrated increased rotation after RTSA with lateralized designs. In a systematic review of studies examining post-operative outcomes in patients treated with a medialized or lateralized COR prosthesis, Helmkamp et al. demonstrated an average improvement of 54° of forward flexion, 62° of abduction, and 21° external rotation in the lateralized COR group vs improvements of 60°, 55°, and 7° in the medialized COR group.[24]

Berglund et al. examined patients with combined loss of active elevation and external rotation as a result of rotator cuff arthropathy or traumatic etiologies who underwent RTSA with a lateralized glenosphere design without a latissimus transfer. They demonstrated a mean improvement in external rotation of 48° (−21° ± 7°–27° ± 18°, $P < 0.001$).[25] A subgroup analysis showed no correlation between Goutallier classification and improvements in external rotation.

2. Conclusion

The Grammont prosthesis is a revolutionary design that has brought the reverse shoulder arthroplasty to the forefront of the shoulder reconstruction. While excellent outcomes and implant longevity have been achieved, post-operative complications such as scapular notching and external rotation deficits have led to the evolution of prosthetic designs that promote a more lateralized center of rotation in order to improve clinical outcomes. BIO-RSA proposes the advantage of placing the center of rotation directly at the bone/prosthesis ingrowth interface and has demonstrated decreased rates of scapular notching. However, higher rates of post operative scapular stress fractures have been reported. Lateralization through the glenoid component has been noted to improve rates of scapular notching and increased anterior joint stability, however concerns over early loosening have been raised. Lateralization through the humeral component is purported to improve efficiency of the remaining rotator cuff and deltoid while also lowering scapular notching rates. Clinical results of lateralized prostheses have demonstrated improved outcomes compared to the original Grammont prosthesis. Further research should aim to elucidate differences in clinical outcomes between LGMH and MGLH prosthesis as well as the optimal combination of the two designs.

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CRediT authorship contribution statement

Steve Parry: Investigation, Resources, Writing - original draft, Writing - review & editing, Project administration. **Shawn Stachler:** Investigation, Resources. **Jared Mahylis:** Conceptualization, Investigation, Writing - review & editing, Supervision.

Declaration of competing interest

The Author(s) declare(s) that there is no conflict of interest.

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