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Lateralisation in reverse shoulder arthroplasty – A narrative review

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ABSTRACT

Reverse shoulder arthroplasty (RSA) has witnessed a significant advancement with the introduction of lateralisation techniques, aiming to enhance shoulder function and implant durability. Traditional medialised designs, following Grammont's principles, have encountered challenges such as scapular notching, reduced rotational strength, and instability. In contrast, lateralisation methods, which reposition the joint center of rotation laterally on the glenoid, humerus, or both, seek to improve deltoid leverage, optimize the rotator cuff muscles' length-tension relationship, and enhance joint stability. Strategies for achieving lateralisation include bone grafts, lateralised glenosphere designs, and metallic augmented base plates. Clinical and biomechanical studies have shown that lateralised RSA designs decrease scapular notching, enhance range of motion, and promote stability. However, these advantages come with drawbacks like heightened shear forces, potential acromial stress fractures, and the risk of joint overstuffing. The future of RSA involves striking a balance between these aspects through tailored implant configurations and the utilization of cutting-edge technologies such as artificial intelligence, 3D modeling, and augmented reality to optimize surgical results. Further research is imperative to validate the long-term efficacy of lateralised RSA and refine these novel approaches to shoulder arthroplasty.

1. Introduction

Reverse Total Shoulder Arthroplasty (RTSA) has become increasingly popular as a treatment of a breadth of shoulder conditions including inflammatory and degenerative arthritis, rotator cuff tear arthropathy and fractures of the proximal humerus. According to the 2022 National Joint Registry report, the number of primary RTSA procedures has surged nearly 4.6-fold, skyrocketing from 687 cases in 2012–3189 cases in 2022.[1]

The 1970s and 1980s saw the first development of reverse polarity designs that included the Leeds shoulder prosthesis,[2] Kessel prosthesis,[3] Bayley-Walker prosthesis[4] and the Liverpool shoulder prosthesis.[5] These initial designs had high failure rates and led to poor functional outcomes with glenoid side failures. The first clinically successful and commercially available prosthesis was designed by Paul Grammont, which was called Trompette" (Medinov®).[6] Grammont's RSA design rationale hinged on the following principles[7].

(I) Medialising the joint center of rotation (JCR), utilizing a 155° neck-shaft angle (NSA), which improves the lever arm of the deltoid during active elevation and abduction movements.
(II) Placing the JCR at the bone-implant interface minimises shear forces exerted on the glenoid component, thus enhancing its stability and longevity.
(III) Distalising the humerus leads to improved recruitment of deltoid muscle fibres, thereby optimizing their function as abductors.
(IV) Utilising a large glenosphere and a semi constrained design to gain increased and stable range of motion

While Grammont design achieves Glenoid implant to bone stability and restoration of elevation and abduction, it has encountered several drawbacks. These include notching, diminished internal and external rotation, implant loosening, instability, and alterations in shoulder contour. Studies have demonstrated that medialisation of JCR results in decreased tension in fibres of anterior and posterior deltoid leading to reduced internal and external rotation strength.[8] Medialisation detensions the anterior and posterior cuff thereby increasing susceptibility to instability. A combination of non-anatomical NSA of 155°, distalisation of humerus and medialised JCR also increases risk of impingement between humerus and scapular neck resulting in notching. This notching triggers polyethylene wear debris generation, leading to osteoclast activation and prosthetic loosening.[8]

Subsequent design modifications with Lateralising the Center of

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Rotation (COR) have been introduced to address the issues with Grammont design. The emphasis has shifted towards lateralisation, which may involve adjustments at the glenoid, the humerus, or both sides concurrently.

1.1. Concept of lateralisation

In RSA, the JCR typically remains medial compared to a natural glenoid joint. The term "lateralised" indicates a relative positioning of JCR that is more laterally positioned in relation to the JCR in original Grammont design. The concept of lateralisation was devised as a solution to counteract the inherent drawbacks associated with a medialised glenoid design in the original Grammont prosthesis.[9] Lateralisation offers to improve the mediolateral force vector of deltoid, length-tension relationship of residual anterior and posterior cuff muscles and wrapping of the deltoid, resulting in increased joint reaction force and stability. The improved tensioning of the residual rotator cuff improves the rotations.[10] Lateralisation can be achieved on glenoid, humerus or both (bipolar/global), however each having different implications.

1.2. Glenoid Lateralisation

Lateralisation on the glenoid side can be achieved in three ways: (1) Using a bone graft under the baseplate known as Bone Increased offset (BIO)- RSA,[11,12] (2) A glenosphere design with lateralised offset,[13,14] (3) Using metallic augmented base plate.[15,16]

Initially proposed by Boileau et al., BIO-RSA technique involves utilising a disc of cancellous bone placed between the native glenoid surface and the glenosphere baseplate. This bone graft is typically an autograft from the excised humeral head. This shifts the glenoid center of rotation to the junction between the cancellous graft and the glenosphere implant, reducing the torque applied to the glenosphere once the graft has healed. In their initial series of 42 patients, with a mean follow up of 28 months, they reported bone healing in 98 % cases with no instances of glenoid loosening or instability. Notching was observed in 19 % patients.[12] In a further study looking at longer follow up Boileau et al. reported bone graft healing in 96 % of cases with BIO-RSA in 143 shoulders with a mean follow up of 75 months. However, notching was observed in 56 % cases with severe scapular notching in 18 % cases. The authors also concluded that glenoid lateralisation alone may not be enough to prevent notching when being used with medialised humeral component (155° NSA).[17]

Glenoid Lateralisation achieved with the use of glenosphere designs with lateralised offset or with the use of augmented base plates is also known as Metal-Increased Offset (MIO)-RSA. In MIO-RSA, the JCR is shifted laterally, away from the bone-implant interface and hence carries risk of increasing the shearing force over the glenosphere and risk of loosening.[14,18,19]

However, Denard and colleagues found in their 3D finite element analysis that metallic lateralisation resulted in lesser stress and displacement compared to BIO-RSA configurations. The authors also suggested that metallic augmentation has the advantages of predictable and planned offset restoration, while reducing the operative time, avoiding the risk of graft resorption or non-union.[20] Ghanta et al. in their systematic review encompassing 810 patients, discovered that augmented baseplates utilised in primary reverse shoulder arthroplasty yield outstanding clinical and functional outcomes. Over a follow up ranging from 16 to 47 months they observed an overall complication rate of 6.4 %. Breaking down these complications into categories, 34.6 % of the complications were attributed to intraoperative or postoperative fractures, 19.2 % were due to baseplate loosening, 5.8 % were linked to instability, and 3.8 % were associated with postoperative hematomas or superficial infections.[21]

Using a larger diameter glenosphere also increases the overall lateral offset of the prosthesis, however it does not lateralise the JCR. It has been demonstrated that increasing the glenosphere size to the next available diameter has very limited impact on the overall offset.[22] While larger glenospheres can enhance arc of ranges of motion, including abduction, internal rotation, and external rotation, they come with notable trade-offs.[19,23] These include potential challenges in surgical exposure and the risk of joint overstuffing. Furthermore, variables such as rotational arcs and joint mechanics are more significantly influenced by glenosphere upsizing than the minor lateral offset it provides. Thus, for lateralisation purposes, alternative approaches that lateralise the JCR are favored over merely increasing the glenosphere size.

2. Advantages of glenoid-sided lateralisation

2.1. Notching

Glenoid-sided lateralisation increases the impingement free range of motion by shifting the JCR laterally and reduces scapular notching. Multiple studies have validated the effectiveness of a lateralised prosthesis in lowering the incidence of scapular notching. Katz et al. reviewed 140 reverse total shoulder arthroplasties (TSAs) using a lateralised glenoid component and found a 29 % incidence of scapular notching after an average follow-up of 45 months. Of these, 92 % were classified as Sirveaux grade I or grade II. The study observed that patients with grade I or II notching did not experience progression at further follow-up, and their functional outcomes remained unaffected.[15] A recent systematic review by Lawrence et al. involving 349 patients, reported that the incidence of scapular notching was significantly lower with lateralised glenoid components compared to shoulders with traditional medialised JCOR glenoid components (5.4 % vs 45 % respectively).[24]

2.1.1. Range of motion

Lateralising the Center of Rotation leads to improved External rotation as observed by Lawrence et al. who reported that the frequency-weighted mean active external rotation was higher (46°) in the lateralised group compared to that in the traditional group (24°).[24]

Adding further to the evidence, a systematic review by Helmkamp et al. that included 18 studies, investigated post-operative outcomes in patients treated with either medialised or lateralised center of rotation (COR) prostheses, showed that patients with lateralised COR prostheses experienced average improvements of 54° in forward flexion, 62° in abduction, and 21° in external rotation. In comparison, those with medialised COR prostheses saw improvements of 60° in forward elevation, 55° in abduction, and 7° in external rotation.[25]

2.2. Stability

The improvements in impingement free range of motion with lateralised RSAs also translate into increased stability compared to medialised RSAs. Guarrella et al., in their muti-center retrospective series of 1035 RSAs studied risk factors for instability and found that lateralisation was associated with lower rates of prosthetic instability.[26] This is consistent with the findings from the cadaveric study by Ferle et al., where they assessed anterior stability at 30° and 60° of abduction with both neutral and 30° external rotation, with lateralised glenoid RSAs with varying lateralisation from 0 to 9 mm and using neck shaft angles of 135°, 145°, and 155°.[27]

The role of subscapularis repair after RSA has long been a controversial topic. Edward et al. in their study using medialised RSA reported a dislocation rate of 9 % in the cases where subscapularis was not repaired compared to 0 % in the repair group. Based on their findings they advocated that subscapularis should be repaired in all cases.[28] On the contrary, Roberson et al. in their study, where they retrospectively evaluated 99 patients who underwent lateralised RSA with or without subscapularis repair, reported no significant differences in functional outcomes and complications including instability between the repair and no repair groups. They suggested that repair of subscapularis after a lateralised RSA is not necessary and is not crucial to stability. Repairing the subscapularis has some potential disadvantages as well, as its antagonistic action can limit external rotation and abduction. Secondly it can delay rehabilitation with restriction of external rotation to protect the repair in early postoperative period.[29]

3. Pitfalls of glenoid-sided lateralisation

Glenoid-side lateralisation in reverse shoulder arthroplasty provides key advantages like reduced scapular notching, increased range of motion, and enhanced stability, but it also comes with certain limitations. The lateral shift of the center of rotation due to glenoid lateralisation significantly increases shearing forces during elevation and abduction. Over time, these increased forces may result in complications such as spine stress fractures or glenoid component loosening, however evidence in literature is inconclusive.

3.1. Glenoid-sided loosening

Lawrence et al. in their systemic review reported higher incidence of glenoid-sided loosening in lateralised RSA compared to medialised RSA (8.8 % vs. 1.8 %, $p = 0.003$).[24] Similarly, in another systemic review, Zumstein et al. observed loosening rates of 5.8 % for lateralised RSA versus 2.5 % for medialised RSA, with the difference being statistically significant ($p = 0.025$).[30] On the contrary, in a more recent systematic review by Rojas et al. encompassing over 6000 RSAs, the difference in loosening between lateralised and medialised RSA was found to be minimal and not statistically significant with the incidence being 1.15 % for medialised RSA and 1.84 % for lateralised RSA.[31]

3.2. Acromial stress fractures

The lateralised offset potentially increases the force required by the deltoid to generate motion, resulting in deltoid related pain and acromial stress fractures. A cadaveric biomechanical study by Wong et al. revealed that among various factors, glenoid lateralisation has the most significant impact on stress levels, leading to a 17.2 % increase (for every 10 mm of lateralisation), whereas humeral lateralisation only causes a 1.7 % increase. The study suggested that a more inferior and medial position of glenoid component would be an effective strategy to minimize stress on the acromion. Additionally, the discussion affirms that medialisation of the humerus also contributes to reducing stress on the acromion.[32] Another similar cadaveric biomechanical study evaluating scapular spine strains with lateralisation revealed that glenoid lateralisation ranging from 0 to 5 mm had minimal impact on scapular spine strains. However, the authors noted that there was a significant increase in strain when lateralisation was increased beyond 5 mm, with highest strain recorded in the Levy zone 2 on acromion. Furthermore, forward elevation resulted in significantly higher strain values compared to abduction.[33]

4. Humeral Lateralisation

The humeral side lateralisation is a function of stem design. The lateralisation on the humerus side can be varied by changing the stem design (straight vs curved), the type of humeral tray (Onlay vs Inlay) and changing the neck shaft angle. Laderman et al. showed that curved stem design increases the lateral offset by the virtue of medialised position of humeral tray and insert. The other advantages that are proposed with a curved stem are that it preserves tuberosity bone stock and cuff insertion, reduced risk of tuberosity fracture, ease of insertion, and the intra-operative & post-operative flexibility to convert between TSA and RSA.[34] In an Inlay type of tray, the stem is embedded in the metaphysis and in an onlay type design the tray sits on top of the osteotomy. An onlay design increases lateral offset by increasing the distance between the humeral shaft and the glenoid. The other advantages of onlay design are that it preserves metaphyseal bone stock, allows additional modularity to change offset by altering the medio-lateral position of insert on the stem.[35,36]

In a recent meta-analysis by Larose et al. that compared inlay and onlay humeral designs for clinical outcomes and complications in 1447 patients with at least 1 year follow up found no definitive superiority of one design in determining clinical outcomes post-operatively. The incidence of scapular notching was noted to be lower with onlay design.[37] Another meta-analysis by Jackson et al. reported similar findings of lower scapular notching with the onlay design (7.74 %) compared to the inlay design (23.18 %). They also noted greater external rotation with the onlay design.[38] This improvement in external rotation with onlay design can be explained by the lateralisation dependent increased rotation moment arm of the posterior deltoid muscle which is the primary external rotator in cuff deficient shoulders.[35]

The NSA is another parameter that can affect the lateral offset in RSA. A higher NSA, results into a more horizontal neck cut and hence medializes the humerus shaft in relation to the glenoid, resulting in lower offset. Laderman et al. in their study comparing various stem designs and their impact on offset and range of motion in RSA showed that keeping other factors consistent, changing the NSA has a minimal impact on offset. These findings were further supported by Werthel et al. in their study where they demonstrated that offset only changed by 3.2 mm between the Delta III stem (NSA 155) and the DJO Altivate stem (NSA 135), where both stems had a straight, inlay design.[22] However, there is plenty evidence in literature for a lower risk of notching with 135° stems compared to 155° stems.[39,40] In a comprehensive meta-analysis encompassing over 2000 RSAs across 38 studies, the incidence of scapular notching was examined with different Neck-Shaft Angles (NSA) of 155° and 135°. Among these cases, an NSA of 155° was utilized in 79.3 % ($n = 1762$), while an NSA of 135° was employed in 20.7 % ($n = 460$), both with a laterally positioned Glenosphere (GS). The analysis revealed a significantly lower occurrence ($p < 0.0001$) of notching in the 135° group (2.8 %) compared to the 155° group (16.8 %).[41]

Humeral lateralisation provides several biomechanical benefits. It places the humerus and the tuberosities in a more anatomical position, restores the length-tension relationship of the residual rotator cuff muscles. This improvement increases the compressive joint reaction force, leading to improved stability.[42] Additionally, a more lateral positioning augments the deltoid lever arm and deltoid wrapping, thereby optimizing deltoid function and reducing potential deltoid fatigue.

4.1. Combined lateralisation and how much to lateralise?

As it is now well established that lateralisation is beneficial in RSA, however the quantification of ideal magnitude of combined lateralisation and the ideal contribution from glenoid-side and humerus-side lateralisation remains uncertain. This variability likely hinges on individual patient factors such as anatomical characteristics, condition of deltoid, integrity of the residual rotator cuff and the extent of humeral distalisation (which affects arm and deltoid length).

Werthel et al. emphasized that primary objective in shoulder arthroplasty is to restore the native optimal tensioning of the remaining rotator cuff, along with restoring the physiological wrapping angle of the deltoid. To accomplish this, they suggested aiming for an average greater tuberosity lateralisation of 0 mm. There is a high variability in the amount of lateralisation that is offered by various prostheses in the market. The authors studied 28 different configurations of 22 RSA prostheses classifying them into various categories based on lateralisation offered. They found that a mean greater tuberosity lateralisation nearing 0 mm is achieved by implants with a global lateral offset between 28.1 and 33.1 mm.[22] Tarallo et al. evaluated clinical outcomes in lateralised RSAs performed with GPS navigation system. The computer navigation system recorded the intra-operative data for glenoid component version, inclination and lateralisation. They discovered that the patients that had glenoid lateralisation between 18 and 22 mm had the best abduction and forward elevation.[43]

Reaping the benefits of lateralisation requires the surgeon to carefully consider patient-specific variables and implant design. An excessive combined lateralisation in RSA can potentially result in complications such as overstuffing of the joint especially in patients with tight soft tissues & small built and difficult intra-operative reduction A patient with an overstuffed joint may experience stiffness and pain. Additionally, an excessively lateralised reverse shoulder arthroplasty (RSA) carries the risk of developing neuropraxia due to overstretching of nerves. Excessive lateralisation has also been found to be related to increased incidence of acromial stress fractures and polyethylene wear.[15,22,44]

4.2. Conclusion and future directions

Reverse shoulder arthroplasty (RSA) has significantly enhanced long-term clinical outcomes and survivorship, prompting its widespread adoption globally. Adoption of lateralisation in the newer implant designs has helped addressing the limitations of the traditional prostheses. While lateralisation offers advantages like reduced notching and improved range of motion, it introduces new challenges such as increased shear forces at the implant-bone interface, risk of acromial stress fractures, and overstuffing of the joint.

The future of RSA involves fine-tuning the equilibrium between ensuring optimal joint stability and functionality, while also minimizing stress on the implant and mitigating potential complications. Artificial intelligence is poised to play a significant role in customizing implant configurations, such as the degree of lateralisation, glenosphere size, and eccentricity. This tailored approach can enhance patient-specific outcomes, such as better range of motion and function, while decreasing the likelihood of issues such as scapular spine fractures or bone resorption. Additionally, further clinical studies with longer follow-up periods are necessary to validate the long-term effectiveness of these advancements and identify any potential drawbacks. Innovative technologies like 3D modeling and augmented reality hold immense potential to revolutionize shoulder surgery. By generating precise, patient-specific virtual models, surgeons can meticulously plan implant placement before surgery. Furthermore, augmented reality can superimpose these virtual plans directly onto the patient during the procedure, providing real-time guidance for optimal implant positioning and enhancing surgical accuracy.[45]

Authors' contribution

KK conceived the idea and design of the article, carried out drafting and editing of manuscript, DG carried out literature review and manuscript writing.

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Declaration of competing interest

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