State of the Art Review

Reverse shoulder arthroplasty: State-of-the-art

Francesco Franceschi a,b,c, Edoardo Giovannetti de Sanctis a,b, Ashish Gupta c, George S. Athwal d, Giovanni Di Giacomo e

a UniCamillus-Saint Camillus International University of Health Sciences, Rome 00100, Italy
b Department of Orthopaedic and Trauma Surgery, San Pietro Fatebenefratelli Hospital, Rome 00100, Italy
c Queensland Unit for Advanced Shoulder Research (QUASR), Queensland University of Technology, Brisbane, QLD 4000, Australia
d The Roth McFarlane Hand and Upper Limb Centre, St. Joseph’s Hospital, London, ON N6A 4V2, Canada
e Concordia Hospital for Special Surgery, Rome 00100, Italy

ABSTRACT

The reverse shoulder arthroplasty conceived by Paul Grammont in 1985 has gradually gained popularity as a treatment for multiple shoulder diseases. Unlike previous reverse shoulder prostheses characterized by unsatisfactory results and a high glenoid implant failure rate, the Grammont design has immediately shown good clinical outcomes. This semi constrained prosthesis solved the issues of the very first designs by medializing and distalizing the center of rotation with an increased stability of the replacement of the component.

The indication was initially limited to cuff tear arthropathy (CTA). It has then been expanded to irreparable massive cuff tears and displaced humeral head fractures.

The most frequent problems of this design are a limited postoperative external rotation and scapular notching.

Different modifications to the original Grammont design have been proposed with the aim of decreasing the risk of failure and complications and improving the clinical outcomes.

Both the position and version/inclination of the glenosphere and the humeral configuration (e.g. neck shaft angle) influence the RSA outcomes.

A lateralized glenoid (whether with bone or metal) and a 135° inlay system configuration leads to a moment arm which is the closest to the native shoulder.

Clinical research will focus on implant designs reducing bone adaptations and revision rate, strategies to prevent more effectively infections. Furthermore, there is still room for improvement in terms of better postoperative internal and external rotations and clinical outcomes after RSA implanted for humeral fracture and revision shoulder arthroplasty.

1. Introduction

1.1. Early reverse prosthesis

Shoulder replacement was originally used as a salvage procedure in severely damaged joints. The early history of shoulder arthroplasty has been widely reported [1]. At the very beginning hemiarthroplasty was used. Although pain relief was obtained, the clinical outcomes reported by physicians were not satisfactory. This was frequently due to a superior migration of the humerus in patients without the stabilizing function of the rotator cuff (RC).

The anatomic total shoulder replacement then started to be used as a treatment for glenohumeral osteoarthritis (OA) and massive RC deficiency. The addition of a glenoid component was supposed to avoid the superior migration. However, the outcomes were not satisfactory due to a high failure rate, mainly caused by an excessive edge loading with the rocking horse phenomenon [1,2].

Patients with both OA and rotator cuff deficiency were defined by Neer as patients with “limited goals surgery” [3]. The main challenge in shoulder replacement was recognized at that time to be increasing the joint stability in patients without a properly functioning RC.

To obviate the need for RC reconstruction different constrained designs were proposed: either with a design reversing the normal anatomy (socket in the proximal humerus and ball in the glenoid) or with higher constrained standard anatomic components.

As the dynamic stabilizers of the shoulder are not functioning properly, the prosthesis design is responsible for preventing the humerus from subluxating superiorly [4]. Reversing the position of the convex and concave surface has this goal.

The intrinsic stability of two prosthetic components depends on the ratio between their depth and diameter: the greater the socket depth the greater the stability of the prosthesis [5,6].

Also matching the radius of curvature between the convex and concave surfaces of the implant increases the stability.

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The higher constrained standard anatomic components were abandoned due to an excessively high rate of glenoid loosening with a failure rate of over 50% [7,8].

Several reverse implant designs were designed during the decades. The majority of those prostheses led to low clinical outcomes and a high failure rate due to glenoid component loosening, implant breakage and anterior instability, as one of the goals in these designs was to match the shoulder's native joint center [4,9,10].

1.2. Grammont design

Paul Grammont in 1985 developed the first generation of a new system differing from the previous reverse shoulder designs [11–13]. Among the key features of this system: a medialized and distalized center of rotation; the glenoid component is uncemented; peripheral screws and a pressfit peg used for glenoid fixation; the humeral part is concave and the glenoid part is convex. Furthermore, in the RSA the center of rotation is shifted from the humeral head to the glenosphere and the humerus is distalized [4,14].

The movement of the shoulder produces a resultant force vector, composed of both compressive and shear forces varying throughout the range of motion that are assumed to cross the glenohumeral center of rotation [4].

The moment of force at the fixation interface is proportional to both the shear forces and the distance between the center of rotation and the implant–bone interface [15]. The medialization of the center of rotation makes the joint forces more compressive and decreases the moment of force at the glenoïd–bone interface [4,15–17]. Lateralizing the center of rotation increases the distance from the bone implant interface resulting in a bigger moment of force [4]. The higher the compressive force, produced by the deltoid and remaining cuff tension, the greater the stability of the shoulder [18,19].

A quantitative measure of a joint stability is the stability ratio, defined as the maximum dislocating force the joint can resist related to a medial compression force.

A normal glenohumeral joint has a stability ratio of approximately 0.5. A total shoulder arthroplasty has a ratio of approximately 1.0 [20,21]. An RSA has a stability ratio >2.0. With the glenohumeral joint in 90% of abduction, the RSA is approximately 4–5 times more stable than a normal joint and 2 to 3 times more stable than conventional total shoulder prostheses [21]. The stability ratio increases approximately 60% with the glenohumeral joint at 90% of abduction and decreases with the arm in a fully adducted position [19].

Thereverse total shoulder replacement relies on the deltoid muscle, instead of the rotator cuff to move the humerus. The RSA design increases the deltoid lever arm as the center of rotation is medialized compared to the anatomic one. Furthermore more deltoid fibers are recruited for abduction, as they are shifted laterally to the center of rotation [22].

The deltoid lever arm is also increased by the distalization of the humerus, as the overall tension produced by a muscle is the sum of active and resting tension [23].

2. Indications

As surgeons have gained more experience with RSA, indications for this procedure have been expanding. The main indication for RSA remains the patient with CTA who has pain, loss of ROM and disabling deltoid weakness [24].

Shoulder osteoarthritis can present with alterations including glenoid retroversion, posterior humeral subluxation, and glenoid bone loss. These features have shown to be associated with inconsistent outcomes and high rate of complications in TSA. Additionally, even if the RC is intact at surgery, tendons do not escape the ageing phenomenon, which can lead to a tear, mainly in the elderly patients (>70).

Young et al. [24] showed that the incidence of secondary rotator cuff tears increased significantly over time after TSA, generating failure with superior translation of the humeral head and narrowing of the subacromial space.

Although RSA has shown satisfactory outcomes in rotator cuff–deficient shoulders, its performance as a treatment for osteoarthritis with an intact rotator cuff optimal outcomes with low complication rates across a short term of follow up. When compared to TSA, RSA shows similar clinical results in patients with osteoarthritis and intact rotator cuff [25–28]. The slightly better postoperative results in studies comparing TSA with RSA may be linked to the differences in distribution of more severe arthritic glenoids, which are more frequently treated with RSA [25].

Before planning a shoulder arthroplasty (e.g. revision RSA) the existence of a prosthetic infection should be excluded, as this would have a devastating effect on clinical outcomes. However, the preoperative diagnosis of infection still remains a challenge, as the none of the preoperative tests (WBC, PMN, ESR, CRP, aspiration and bone scan) have shown to be reliable [29]. The diagnosis is therefore based on the combination of clinical exam, elevation of inflammatory markers, and intraoperative findings.

Other reported RSA contraindications include axillary nerve damage and nonfunctioning deltoid muscle, as the latter represents the main motor muscle in RSA and is closely correlated with postoperative outcomes.

The deltoid should be assessed preoperatively clinically, evaluating the muscle strength for forward elevation, abduction, and extension, and in terms of morphology (volume and fatty degeneration) [30,31].

3. Surgical technique

Under general anesthesia, the patient is placed in a beach chair position with the arm in holder [32,33].

Two are the approaches used in accessing the glenohumeral joint during RSA: the deltopectoral approach and the anterosuperior approach. Due to their anatomic location, they both have distinct advantages and disadvantages. The deltopectoral approach is generally preferred.

The rotator cuff and biceps are assessed precisely. The long head of the biceps is systematically cut. The subscapularis is prepared with resorbable sutures.

Different exposure techniques have been described to manage the subscapularis, the most common include: tenotomy, peel and lesser tuberosity osteotomy. The tenotomy involves an intratendinous division, whereas the peel completely detaches the subscapularis insertion from the lesser tuberosity. The lesser tuberosity osteotomy maintains the subscapularis tendon attachment to the tuberosity. Each subscapularis management technique has been shown to be effective and safe in the short term with no proven difference [34].

Capsulotomy and humeral head dislocation are then performed. The anatomical neck is identified. When needed a dedicated guide might be used to harvest a cylindrical or angled autograft from the humeral head. A resection of the humeral head is then performed according to the preoperative planning and frequently 2 mm below the articular cartilage. Each prosthesis has its own cutting guide depending on the design and the characteristics. The extent of retroversion is chosen by the physician.

The effect of humeral component retroversion on clinical outcomes is unclear. Although a final opinion has not been yet expressed on the matter, the general consensus tends to agree on restoring 0° to 20° of retroversion of the humeral [35]. Increasing humeral retroversion has been shown to increase ER and decrease IR [36].

The medullary canal and metaphyseal zones are then prepared based on the stem design used.

Once the humeral stem size has been decided, the component is left within the canal to avoid creating any fractures while preparing the glenoid.

To expose the glenoid articular surface the labrum is excised completely. A circumferential periglenoid capsulotomy is carried out.
The glenoid surface might be fully exposed. Several glenoid retractors have been developed (e.g. Hohmann, Fukuda). The cartilaginous surface might be removed with a curette. It is mandatory to identify the inferior margin for proper baseplate seating.

Different intraoperative instrument guidances (e.g. 10° inferior tilt guide, PSI, Navigation) have been developed for glenoid reaming and baseplate positioning.

A k-wire is frequently used as a guide for the glenoid reamer. The direction of the k-wire corresponds to the direction of the baseplate central peg. Reaming and baseplate positioning are based on the preoperative planning and should avoid excessive retroversion and superior inclination. Excessive reaming should be avoided to preserve the bone stock.

Different intraoperative instrument guidances (standard glenoid guides, PSI and Navigation) have been developed for k-wire placement and therefore glenoid reaming and baseplate positioning as accuracy of the previously described method to measure is limited.

Based on the instrumentation used, the surgeon might have a single glenoid guide with 2 or three pin holes (0°/10°/20° of inferior tilt) or different augmented glenoid plate drill guides within the same system.

The use of patient specific guided glenoid components (PSI) and/or navigation help to intraoperatively accomplish implantation of the glenoid baseplate according to the preoperative 3D planning [37].

The drill guide should be placed into the glenoid surface making sure that its bottom surface is perfectly seated on the bone. Once it is positioned a single use alignment pin should be inserted and drilled until a trans-cortical fixation is obtained.

After the reaming is performed the baseplate is then impacted with or without the medially placed humeral bone autograft. It is then fixed with usually 2 to 4 screws, depending on the model implanted. The goal is to place the screws as long as possible to increase the stability of the implant. The directions of the superior and inferior screws are respectively the coracoid and the scapular pillar. The other two screws might be placed convergent or divergent to the central peg. The trial glenosphere is then placed.

The trial humeral components are positioned and the prosthesis is reduced. The muscular tension is then tested to evaluate if the metaphyseal tray and insert sizes are correct.

The joint stability is then tested also by moving it in all directions and with slight traction along the body. It is also mandatory to evaluate there is no impingement especially in adduction and abduction. Once the components have been chosen, implant of the final components is performed beginning with the glenosphere. The subscapularis is repaired to its insertion.

Controversial is whether a drain should be placed in the subacromial space at the end of the procedure [38]. The incision is closed.

The surgical technique might be modified based on patient demographics such as BMI, gender and age. A higher BMI influences the surgical procedure often leading to increased operative times. Shoulder exposure is more challenging due to a greater soft tissue envelope with an increased glenoid depth. Furthermore, positioning the arm in adduction during humerus preparation may be difficult due to an increased size of the arm and torso. Additionally the greater weight of the arm might be associated with a higher risk of dislocation, therefore the soft tissue tension should be assessed with caution [39].

Gender-related anatomical differences may have implications when considering reverse shoulder arthroplasty. Male patients have significantly larger glenoid and humeral heads and more muscular deltoids and pectoralis major muscles; this may result in longer exposure times and therefore a total operating procedure taking a mean of 9 min longer [40].

In addition, men in general are larger than women and require slightly larger incisions, which can take longer to open and close [40].

It has been shown that a larger extent of muscle fatty infiltration progression is usually detected in females and in older patients. Additionally, older patients had significantly higher levels of muscle retraction [41]. This may have an implication in rotator cuff repair at the end of the procedure and clinical outcomes in terms of internal and external rotation.

Diabetes and peripheral vascular disease which are more frequently reported in older patients have been associated with a higher risk of complications and peri-operative mortality (e.g. infection) [42], and have an implication in perioperative patients management.

4. Subscapularis repair in RSA

Debated is whether the subscapularis should be repaired in RSA [43]. Theoretically repairing the subscapularis should improve the glenohumeral stability decreasing the risk of dislocation.

This recommendation should be taken into account for medialized designs; whereas not repairing the subscapularis with a lateralized design has not shown to result in a greater risk of glenohumeral instability. This effect is due to the deltoid wrapping producing a more compressive joint load in lateralized designs [44].

Furthermore, it has is still controversial whether repairing the subscapularis influences the clinical postoperative ROM, in terms of internal and external rotation and abduction.

Dedy et al. assessed 48 RSA performed with subscapularis repair [45]. The tendons were evaluated with ultrasounds. 46% were graded as “intact” vs. 54% as “not intact.” The first group showed a significantly higher IR.

Collin et al. [46] performed a similar retrospective review of 86 patients at 2 years follow up. The authors revealed that 52.6% of patients had a healed tendon, showing a significantly better IR and no difference in ER.

Some authors believe that this might decrease the postoperative abduction as in RSA the subscapularis is shifted inferiorly to the center of rotation, becoming an adductor for almost the entire range of motion, producing an antagonistic effect that increases deltoid and joint loading [22,44,47,48].

5. RSA in intact rotator cuff

The RSA at the beginning was indicated only for RC arthropathy and massive RC tears [47]. These indications have then been expanded including also glenohumeral arthritis with glenoid deficits classified as > A2, according to the Walch classification, even with an intact rotator cuff [44,49,50]. The surgeon thus has the option to preserve or release the rotator cuff in these scenarios. The aim during the surgery is to preserve the posterosuperior cuff, even though it is frequently necessary to release the supraspinatus tendon, if still intact, to avoid excessive tension and difficulties in reducing the RSA [51].

6. RSA prosthesis design classification

A classification system has been proposed by Routman et al. to categorize the different RSA designs, based on the glenoid and humeral components characteristics [52]. Glenoid components might be classified as medialized or lateralized based on the center of rotation position [53]. The position of the center of rotation is determined by the glenosphere thickness and radius and the use of bone or metal augments.

Humeral components are divided in medialized and lateralized based on the distance between the intramedullary canal axis and the center of rotation of the humerlar liner. This distance is influenced by humeral NSA, the tray and inserts thickness and osteotomy height.

The implants are therefore classified as: MedG-MedH (medialized glenosphere-medialized humerus), MedG-LatH (medialized glenosphere-lateralized humerus), LatG-MedH(lateralized glenosphere-medialized humerus), LatG-LatH (lateralized glenosphere-lateralized humerus). Each of these 4 configurations has pros and cons.

This classification has been further modified by Werthel et al. according to the specific characteristics of different RSA designs [54].
6.1. Medialized glenosphere

This configuration, which is part of the Grammont design, is characterized by a greater center of rotation medial shift. This theoretically would increase the abductor moment of the deltoid, requiring less force to elevate the arm. Furthermore, a medialized center of rotation converts shear into compressive forces at the baseplate–bone interface improving component integration and fixation [22, 55, 56].

However, this configuration might lead to decreased external and internal rotation, due to a reduced amount of respectively posterior and anterior deltoid/residual RC, therefore reducing the horizontal stabilizing compressive forces with an increased risk of instability and scapular notching [55–58].

6.2. Lateralized glenosphere

A glenosphere is defined as lateralized compared to the Grammont design. However, it is worth remembering that this configuration center of rotation is still medialized compared to an anatomic shoulder. Lateralization is achieved by using an eccentric glenosphere or using a bone or metal graft.

This design improves deltoid wrapping which might decrease the risk of dislocation [55].

Furthermore, lateralizing the center of rotation has been suggested as a way of improving external rotation by retensioning the posterior rotator cuff (lengthening the origin-insertion distance) and recruiting more fibers of the deltoid for external rotation [4, 59]. Also anterior rotator cuff could be increased by lateralizing the glenosphere as a result of decreased contact with the anterior glenoid and coracoid as shown by Giles et al. [44].

In addition, Gutierrez et al. showed that the factor with the largest effect on ABD increasing the superomedial space over the Glenosphere was center of rotation lateralization [60].

Conversely, with this configuration as the center of rotation moves closer to the deltoid line of pull, the force required by the deltoid for abduction might increase with negative implications on ROM and higher risk of stress fractures [47, 51, 54, 55]. In addition, the glenoid implant is subjected to higher shear forces, as the center of rotation in lateralized eccentric glenospheres is not at the bone-implant interface, which could facilitate glenoid loosening [54].

The Bone Increased Offset Reverse Shoulder Arthroplasty (BIO-RSA) has been proposed to address the problems of medialized design bringing the potential advantages of glenoid component lateralization without increasing the distance between the center of rotation and the implant–bone interface [59, 61–63] (Fig. 1).

Excessive lateralization may cause acromion and scapular spine stress fractures [51].

6.3. Medialized humerus

This configuration, which is part of the Grammont design, is characterized by an inlay metaphysis and a 155° NSA humeral stem. It shifts the humerus medially and distally to increase deltoid tensioning.

This configuration would: shorten the remaining RC affecting negatively postoperative internal and external rotation, increase the risk of scapular notching, increase the abduction passive ROM therefore reducing the risk of acromio-humeral impingement in abduction [4, 6, 58].

6.4. Lateralized humerus

A humerus might be lateralized reducing the NSA (from 155° to 135°), increasing the tray or insert thickness, using an onlay instead of an inlay metaphyseal component or by shifting the humerus laterally by dialing and positioning the long distance of the onlay eccentricity medially [51].

The tray is described as “onlay” when positioned on the anatomical neck osteotomy, “semi-inlay” if half of it is positioned distal to the neck osteotomy, and “inlay” if it is completely within the metaphysis distally to the anatomical osteotomy.

Using a lateralized humerus has several advantages. It restores a more anatomical position of the lesser and greater tuberosities, improving the length/tension curve of the remaining cuff.

A lateralized humerus/greater tuberosity increases also the deltoid abductor lever arm and wrapping angle [14, 54, 58].

Giles et al. showed that this configuration produces a compressive shift in the joint loading angle [44]. This result is desirable as it improves glenosphere baseplate fixation, which is fundamental for promoting osseous integration in the early postoperative phase.

6.5. Effect of RSA design parameters on RC and deltoid muscles torques

Several problems have been associated with the Grammont design, mainly the scapular notching and a post-operative external rotation deficit [47, 52].
Due to its non-anatomic design and to still unclear biomechanics, the ideal RSA configuration and the effects of on RC and deltoid moment arms is a debated topic.

As said previously, a force producing active motion through a joint is schematically composed of two components: one perpendicular to the lever arm (rotatory component) and one parallel to the lever arm (stabilizing component).

The force \( F \) is applied by the tendon at its insertion \( P \). The lever arm \( L \) is the perpendicular distance between the line of action of the force and the center of rotation \( C \). The moment of force is a measure of its tendency to rotate a body about a specific point and depends on both the force, and on the lever arm (Fig. 2).

Torque and moment arm are a measure of the effectiveness of a muscle to a specific motion.

The four RSA configurations and a native shoulder were compared in three planes of motion: scapular plane when considering abduction by action of the deltoid, axial plane when considering external rotation by the action of the deltoid and infraspinatus (Fig. 2) and sagittal oblique plane when considering external rotation by action of the teres minor muscle.

Di Giacomo with his team performed an unpublished computational biomechanical analysis to assess moment arms and torque intensity of deltoid, infraspinatus and teres minor both in the native and in these 4 prosthetic reverse shoulder categories. It confirms that the RSA moves the center of rotation medially (2.25 cm in a MedG and 1.25 in. LatG) and leads to an increased moment arm in each pattern compared to an anatomic shoulder (Fig. 3).

Although the MedG/LatH configuration leads to the highest torque value for all examined muscles, the LatG/MedH configuration leads to a moment arm which is the closest to the native shoulder (Fig. 4).

Although this study confirms the results of previous articles, the optimal amount of glenoid lateralization is still controversial.

7. Clinical outcomes and complications

The RSA has shown to be an effective treatment in decreasing pain leading to better shoulder function. The indications for this surgery are RC arthropathy, massive RC tears, glenohumeral osteoarthritis with a big glenoid bone defect and proximal humeral fractures.

Although during the last two decades the number of RSAs implanted per year has increased exponentially, the improvement in surgical technique, implant positioning and component designs has reduced the rate of complications and therefore revisions [64,65].

In the literature the complication rate varies from 0 to 75%, with an overall value of 9.4% [64]. Revision rate at 2 years has been shown to be 2.6% [64].

At two years RSA has demonstrated to increase ASES (from 36.7 to 67.6) and constant (from 32.2 to 69.0) score, decreasing shoulder pain. Active anterior flexion, abduction and ER improved, respectively 56°, 50° and 14° [64]. The RSA has been shown to lead to an improvement in patient function and activity of daily living.

The long-term results have been just recently reported. De La Selle retrospectively evaluated a consecutive series of shoulders at a minimum follow-up of 7.4 years, showing a revision rate of 3% and an absolute CS of 59.0 ± 16.2 [66].

Chelli et al. reported a survivorship of 91% in a large series of primary RSAs evaluated at 10 years [67]. The authors showed a lower survival rate for fracture sequelae and tumors, respectively of 83.9% and 53.1%.

Fig. 3. Whatever the configuration, the RSA moves the CoR medially.
Sheth et al. evaluated 94 patients with a minimum of 10 years' follow-up, showing no deterioration in function or pain from midterm to long-term [68]. Patients were described as very satisfied (56%) satisfied (26%) dissatisfied (14%) and very dissatisfied (4%). The survival rate was shown to be 81% at 10 years.

Bacle et al. reported the outcomes after a minimum of 10 years [69]. The authors showed a high arthroplasty survival rate (93%) and good long-term clinical results despite highlighting deterioration in clinical outcomes when compared with medium-term results.

When the RSA is used as a treatment for proximal humeral fractures the post-operative clinical outcomes have been shown to be worse.

Zumstein et al. differentiated “complications” from “problems” evaluating events associated with RSAs. Complications have been defined as events affecting clinical outcomes.

Most common complications associated with RSA are: acromial and scapular fractures, instability, aseptic glenoid and humeral loosening, infection, humeral fractures, and nerve injuries. The most common problem is scapular notching. Furthermore, the replacement might change the stress distribution in the proximal humerus, with bone adaptations.

The incidence of complications has been changing over time. During the last decade infection seems to be outpacing instability, becoming the first cause of complication [65,70]. The decreased rate of dislocations might be due to improvements in design and surgical skills.

The acromial and scapular fracture rate ranges from 1% to 4% [64]. Elderly females with osteoporosis have a higher risk of these fractures. Furthermore, the design of the RSA implanted influences this value: the Grammont RSA is associated with a higher rate.

These fractures might be caused by trauma (fall on the ground) or by an increased tension of the deltoid (stress fracture) and have been classified by Levy et al. in three types [71].

Overtensioning the deltoid by distalizing humerus has been shown to be the main risk factor for stress fractures [72–74].

Lädermann et al. [74] stated that arm lengthening more than 2.5 cm compared with the contralateral side might increase the risk of stress fracture.

The placement of the baseplate superior screw with a direction towards the base of the scapular spine has been advocated as a risk factor for these fractures. Orienting the screw towards the coracoid reduces significantly the rate of scapular fractures [75].

The treatment strategy to be used with these fractures is still controversial. Surgery has not been associated with significant higher postoperative clinical outcomes. A conservative treatment with a sling in abduction for 4 weeks is more frequently used. Operative treatment with plate fixation might be considered in younger patients with high functional demands.

This complication lead to inferior outcomes when compared to RSA without any associated fractures [76].

The rate of glenohumeral instability after RSA has been shown to be 1.4% [64]. With improvements in prosthesis designs the rate of dislocations seems to be reducing [77,78].

The RSA stability is influenced by soft tissue and impingement free arc range of motion. The risk factors for RSA dislocation are: previous surgery, lack of soft tissue tension, improper version/inclination of the implant [79].

Although this design increases the glenohumeral joint stability, a good soft tissue envelope is mandatory to avoid anterior and posterior dislocations.

The soft tissue tension changes with different RSA designs: in Grammont designs, failure to restore sufficient soft tissue tension may result in prosthetic instability.

The subscapularis which is considered a protector against anterior dislocation in TSA and medialized RSA (Grammont design), might be not necessary in lateralized RSA implants, as the whole compression needed is carried out by the deltoid [80].

In revision surgery, soft tissue tension might be also reduced due to shortening of the humeral height, compared to the normal opposite side (Proximal Humeral Bone Loss – PHBL).

Deltoid and RC tension might be increased by distalizing and/or lateralizing either the glenoid and humerus [21,73,81–83].

The infection rate has been reported by Ascione et al. to be 4.1% [70]. Prior shoulder surgery (e.g. arthroscopic rotator cuff repair), obesity, rheumatoid arthritis, malnutrition and long operation time increase the risk of this complication [79]. Cutibacterium acnes (formerly Propionibacterium acnes) which is the most common pathogen, is normally present on the skin and takes up to 14 days to be

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**Fig. 4.** The LatG/MedH configuration leads to a moment arm which is the closest to the native shoulder.
detected from the culture [84].

Classically, periprosthetic shoulder infections might be classified into acute (one to three months), subacute infection (four to 12 months) and late infection (>12 months), depending on the time of diagnosis after the surgery [85].

Periprosthetic infection of the shoulder represents a difficult diagnostic challenge since it often presents without the typical signs and symptoms such as drainage and erythema [86].

Common screening makers such as C-reactive protein (CRP), and serum erythrocyte sedimentation rate (ESR), lack diagnostic reliability in the shoulder. Pre-operative aspiration has been proposed for infection diagnosis [85,86].

However, because of the low sensitivity of bacterial cultures after arthrocentesis, some surgeons advocate for arthroscopic tissue biopsy, but still debated is the number of samples (usually more than three) to be performed to optimize the sensitivity and specificity of diagnosis.

Still debated is also the preferred treatment strategy. In acute (<45 days) infection open irrigation, debridement and exchange of polyethylene might be an option. In chronic (>45 days) infection, a two stage revision is the gold standard with better clinical outcomes.

Aspectic glenoid loosening may be caused by poor bone stock, excessive version/superior inclination, the design of glenoid components, the technique of fixation and excessive joint reaction forces.

Glenoid bone defect correction is mandatory and might be performed through an eccentric reaming and/or the use of bone grafts (e.g. Bony Increased Offset) or augmented baseplates [87]. Excessive reaming should be avoided as it is associated with subchondral bone weakening with loss of bone volume and surface area. Augmenting the baseplate with bone or metal, preserve bone stock enhancing the baseplate fixation and increasing the implant lateralization.

The central fixation element is the main responsible for baseplate stability. The number of peripheral screws to be placed depends on the design of the glenoid component. Glenoid component failure rate has reduced tremendously after the introduction of locking screws [88]. Optimal screw placement maximizes screw length, accomplishes far cortical fixation, and attains screw purchase in good bone stock [89].

The compressive forces act on the glenoid side as stabilizers, whereas the shear forces act in a direction parallel to the glenoid and might lead to the component loosening [90].

Aseptic stem loosening is not common, occurring more frequently in longer follow-up [91]. No difference has been shown in terms of stem loosening between cemented and uncemented stems.

Nerve injury might be caused by transection (electrocautery), thermal injury (cement extrusion) or excessive compression (e.g. retractors), traction (e.g. arm lengthening, intraoperative positioning), pressure (hematoma). The nerves at higher risk are the axillary, radial, supraclavicular, and brachial plexus nerves.

Uncommon and difficult to manage, the periprosthetic fractures occur more frequently on the humeral side, during impaction or arm positioning [92].

While treating humeral fractures, it is mandatory to reach the stem stability. With a stable stem, the fracture might be fixed, otherwise the stem should be replaced with a longer cemented one [93].

Scapular notching is due to the humeral socket impinging with the scapular neck in extension, adduction and external rotation with PE erosion, joint inflammation and a higher risk of implant loosening [14, 94,94].

This was a very common radiographic finding with the first RSA designs, with rates up to 96%. A medialized center of rotation, which is one of the Grammont design characteristics, would increase the risk of this event.

The scapular notching was first reported and classified by Sirveaux [94]. The classification, based on true AP radiograph, divides this phenomenon in five grades: grade 0: no notch; grade 1: notch contained within the inferior pillar; grade 2: notch extension under the inferior screw; grade 3: notch extension over the inferior screw; grade 4: notch extension under the peg [95–97].

Several factors are associated with a higher risk of scapular notching [98], which include, the glenoid baseplate version and inclination, neck-shaft angle, length of the scapular neck, and position of the center of rotation [99,100].

Positioning the glenosphere with inferior overhang, inferior tilt and lateralization has been proposed as the optimal combination on the glenoid side to reduce scapular notching risk [51,59,101–103]. The development of new designs with a lower NSA has decreased the scapular notching rate.

An inferior overhang of the glenosphere to the bone, from 0 mm to 5 mm, might decrease the risk of both this problem and impingement during abduction, due to an increased distance between the greater tuberosity and coracacromial.

Still debated is whether there exists a correlation between scapular notching and clinical outcomes.

The evolution of the humeral component design is continuing with the goal of improving survivorship and patient clinical results. Short uncemented stems have been developed to preserve proximal humeral bone stock and reduce remodeling and bone adaptation.

Still debated is whether bone adaptation and remodeling is more frequently detectable in Onlay than Inlay systems.

The Onlay prosthesis has been criticized due to its non anatomic design, an increased risk of fracture (additional humeral lateralization and distalization), a greater difficulty in suturing the subscapularis. A theoretically increased deltoid wrapping and greater bone stock preservation have been proposed as strengths of this design [104,105]. Furthermore with this system the tray offset might be changed, influencing the position and medio-lateralization of the humerus.

An Inlay implant seems to have better bone integration and thus better humeral fixation with less risk of proximal stress shielding and loosening. Lower deltoid tension is associated with a reduced risk of scapula spine fracture and a lower risk of neurological injuries [106,107].

Return to sports after reverse shoulder arthroplasty is possible and highly frequent with no change or improvement in subjective level of practice in most of the cases [108].

8. Clinical outcomes based on implant design

Berton et al. in their systematic review compared medial COR or lateral COR [109]. The authors showed that both implant designs predictably improve patient’s function and reduce their pain. Lateral COR was associated with significant better postoperative improvement in external rotation with arm-at side (20.4° and 8.3), scapular notching rates (6.6% and 47.7%) and lower post-operative infection rates (1% and 7.7%). However the statistically significant difference in reinfection between lateralized and mediolateralized RSA could be influenced by the different duration of follow-up as stated by the authors.

Also Cho et al. confirmed that lateralized center of rotation rsa lead to greater improvement in ER degree, a lower VAS pain score and a lower rate of scapular notching and no significant changes in functional outcome scores or the complication rate [110].

Kim et al. compared glenoid-based lateralization (LG) and humerus-based lateralization (LH) [111]. They authors concluded that the outcomes and occurrence of complications were not significantly different between the two lateralized prosthesis groups. However, when the subscapularis was repaired, LH prosthesis seems to be more suitable to obtain a better ASES score and ROM.

9. Geographical differences

Most studies with measurements and suggestions on optimal components position in RSAs are performed in predominantly Caucasian populations [112].

However Asian (e.g. Chinese, Japanese) bony dimensions of the shoulder have been found to be different from that of the Caucasian population.
Asian glenoids and proximal humeral heads are smaller [113].

Iannotti et al. [114] found a mean glenoid height and width of respectively 39 ± 3.5 mm and 29 ± 3.2 mm. Von Schroeder et al. [115] reported a mean glenoid height and width pf respectively 36 ± 4 mm and 29 ± 3 mm.

Matsumura et al. [116] evaluated one hundred-sixty shoulders and reported a mean glenoid height and width of respectively 31.5 ± 2.8 mm and 23.1 ± 2.4 mm. Shimozono et al. [117] reported in a Japanese population that the mean glenoid height and width are respectively 33.3 ± 5.3 mm and 25.9 ± 4.3 mm.

As reverse shoulder arthroplasties should match the dimensions of the native bony anatomy some changes for optimal baseplate positioning have been proposed for small stature Asian women to decrease the risk of complications [113].

Additionally, in a small glenoid the standard-sized 29 mm is larger than bone stock, leading to insufficient bone-component contact. To solve this issue some manufacturers have made available baseplates with a diameter smaller than 29 mm [118,119].

Sahu et al. compared the Western with the Chinese and Japanese Population. The authors found a smaller humeral radius of curvature, articular surface diameter, inclination angle and a larger humeral head [120]. These geographically differences should be taken into account when planning a reverse shoulder arthroplasty.

10. Conclusions

A lateralized glenoid (whether with bone or metal) and a 135° Inlay system configuration leads to a moment arm, which is the closest to the native shoulder.

In addition to the intrinsic characteristics of the prosthesis, patient selection remains a fundamental step to get the best clinical outcomes.

The ideal RSA configuration most certainly depends on the individual, and patient specific factors need to be respected and taken into account.

Clinical research will focus on implant designs reducing bone adaptations and revision rate, strategies to prevent more effectively infections.

Furthermore, there is still room for improvement in terms of better postoperative internal and external rotations and clinical outcomes after RSA implanted for humeral fracture and revision shoulder arthroplasty.
Box 4. Key issues for patient selection

**Indication**
- Pain
- Deficient shoulder ROM (forward flexion)
- Deficient ADL
- Radiographic diagnosis of Glenohumeral Osteoarthritis with RCT
- RCT in a patient >70 years old
- Exclude previous infection
- Well-functioning Deltoid muscle

**Preoperative planning evaluation**
- Evaluate Glenoid vault and proximal humerus bone stock (implant choice)
- Evaluate active external rotation (tendon transfer)
- Posture and Scapulothoracic evaluation (implant position)
- Deltoid muscle evaluation (implant position)

Box 5. Tips & tricks

- Correct and lateralize as much as possible the glenoid surface whether with metal and/or bone autograft
- Add as many screws as you can maximize baseplate fixation
- Aim to place the glenoid with a slight inferior tilt
- The 135° neck shaft angle more anatomical, less scapular notching, and favorable
- In order to prevent axillary nerve injury, caution should be used during periosteal detachment in glenoid preparation.
- The use of arm support would decrease the brachial plexus strain
- Avoid excessive traction while placing the arm in excessive external rotation, extension and abduction at risk
- Ream and impact carefully the humeral component to avoid humeral fractures.
- Broaching parallel to the humeral shaft and avoid excessive fitting of the humeral stem
- To prevent periprosthetic infections:
  1. bathing with chlorhexidine gluconate on the day before surgery,
  2. administration of cephalosporin as a preventive antibiotic 1 h before surgery,
  3. changing surgical gloves regularly,
  4. changing the blade after skin incision,
  5. frequent surgical site irrigation (also with diluted povidone),
  6. injection of gentamicin at the time of closure
  7. use of antibiotic-loaded cement (1 g of vancomycin/bone cement)

Box 6. Major pitfalls

**Perioperative**
- Proximal humeral bone loss
- Massive eccentric/concentric glenoid vault erosion
- Intraoperative humeral fracture
- Nerve injury
- Coracoid fracture in during navigation
- Perioperative hematoma

**Postoperative (at follow-up)**
- Periprosthetic infection
- Dislocation
- Periprosthetic fracture
- Scapular notching
- Acromion or scapular spine fracture
- Aseptic loosening of prosthesis

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