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SHORT COMMUNICATION

20 YEARS OF RSP – THE 5 MOST IMPORTANT LESSONS I'VE LEARNED

20 LAT RSP – 5 NAJWAŻNIEJSZYCH LEKCJI, JAKICH SIĘ NAUCZYŁEM

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ABSTRACT
Introduction and aim
This paper reports on 5 key aspects to consider when planning a successful RSA procedure, including patient selection, glenosphere positioning, glenoid fixation, humeral fixation, and soft tissue management/tensioning.

Material, methods, results, and discussion
Key in patient selection for RSA is understanding the relationship between indications, outcomes, patient mental state, and their expectations. When placing a glenosphere, prioritize sound principles of shoulder kinematics but always consider bone preservation and ease of placement. Glenoid fixation must take advantage of structural features of individual implant designs while factoring in specific-bone morphology/morphometry to optimize the resultant glenohumeral loading. For the stem, fixation prioritizes press-fit where bone quality and quantity permit. Always aim to achieve anatomical pivot point restoration with planning for stem position and avoid distalization that may lead to nerve injury and scapular spine fractures.

Conclusions
To increase the chances of a successful RSA procedure, a surgeon should emphasize picking the right patient, placing the implant in an optimum position, ensuring adequate glenoid and humeral fixation, and correctly balancing soft tissues.

Keywords: reverse shoulder arthroplasty, surgeon education, patient optimization

STRESZCZENIE
Wstęp i cel
Niniejszy artykuł opisuje 5 kluczowych aspektów, które należy wziąć pod uwagę przy planowaniu udanej procedury RSA, w tym wybór pacjentów, pozycjonowanie stawu ramiennego, stabilizację panewki stawowej, stabilizację kości ramiennej oraz zarządzanie przy napinaniu tkanek miękkich.

Materiał, metody, wyniki i dyskusja
Kluczem w doborze pacjentów do RSA jest zrozumienie związku między wskazaniami, wynikami, stanem psychicznym pacjenta i jego oczekiwaniami. Podczas operacji stawu ramiennego

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należy priorytetowo traktować zasady kinematyki barku, ale zawsze brać pod uwagę zachowanie kości i łatwość umieszczenia. Mocowanie stawu ramiennego musi wykorzystywać cechy strukturalne poszczególnych projektów implantów, jednocześnie uwzględniając specyficzną morfologię/morfometrię kości, aby zoptymalizować wynikowe obciążenie kości ramiennej. W przypadku mocowania trzpienia priorytetem jest jego dopasowanie tam, gdzie pozwala na to jakość i ilość kości. Należy zawsze dążyć do osiągnięcia anatomicznej odbudowy punktu obrotu z planowaniem pozycji trzpienia i unikać dystalizacji, która może prowadzić do uszkodzenia nerwów i złamań.

Wnioski
Aby zwiększyć szanse na powodzenie zabiegu RSA, chirurg powinien położyć nacisk na wybór odpowiedniego pacjenta, umieszczenie implantu w optymalnej pozycji, zapewnienie odpowiedniego mocowania panewki i kości ramiennej oraz prawidłowe wyważenie tkanek miękkich.

Słowa kluczowe: odwrócona endoprotezoplastyka stawu barkowego, edukacja chirurga, optymalizacja pacjenta.

Introduction and aim

Despite its late adoption in the United States (US), reverse shoulder arthroplasty (RSA) has become the most common form of shoulder arthroplasty performed in the US. A study done in 2011 estimated that out of the 66,485 shoulder arthroplasties performed that year, 33% were RSAs (Schairer *et al.,* 2015; Westermann *et al.,* 2015). This percentage has likely increased substantially due to the wide range of indications added since 2011. Initial indications focused on rotator cuff arthropathy but have expanded to include inflammatory arthritis, acute proximal humerus fractures, revision surgery, shoulder dysplasias, glenohumeral osteoarthritis with severe bone loss, aseptic necrosis, and chronic glenohumeral dislocations (Ryan *et al.,* 2020; Westermann *et al.,* 2015). Charles Neer is often accredited with the development of the first functional reverse prosthesis in the 1970s to treat patients with rotator cuff arthropathy. After three failed iterations (Mark I, Mark II, Mark III) of his prosthesis, he abandoned the idea concluding that rotator cuff repair was superior in every aspect (Flatow *et al.,* 2011). Meanwhile, Paul Grammont was developing a reverse prosthesis design of his own. His reverse prosthesis was introduced in 1985 and built upon the design of Neer's prosthesis, focusing on 4 key principles: (1) the center of rotation (COR) must be fixed, distalized, and medialized to the level of the glenoid surface; (2) the prosthesis must be inherently stable; (3) the lever arm of the deltoid must be effective from the start of the movement; and (4) the glenosphere must be large and the humeral cup small to create a semi-constrained articulation (Boileau *et al.,* 2009; Grammont *et al.,* 1987).

In 1991, Grammont further medialized the COR and coated the glenoid baseplate with hydroxyapatite to improve fixation. This model was termed the Delta III (Flatow *et al.,* 2011). Whereas some of these principles are partly true today, many of them have proven to be recommendations more than principles (Werthel *et al.,* 2019). I have spent the last 20 years developing my principles and recommendations.

The aim of this review paper is to take the experience of performing RSAs for over 20 years and summarize it into 5 key concepts: patient selection, glenosphere positioning, glenoid fixation, humeral fixation, and soft tissue management/tensioning.

Material, methods, results, discussion

Lesson 1: Patient Selection

After multiple iterations and re-designs, the RSA began to show significant improvements in clinical outcomes. Early reports provided some evidence that postoperative outcomes are related to indication (Wall *et al.,* 2007; Boileau *et al.* 2009, Mulieri *et al.,* 2010). The current list of expanding indications includes massive cuff tear without osteoarthritis (MCT without OA), massive cuff tear with osteoarthritis (MCT with OA), osteoarthritis (OA) with intact cuff, proximal humeral fracture, scapular fracture, severe glenoid bone loss, revision settings after hemiarthroplasty/ anatomic total shoulder arthroplasty (TSA) and RSA, and tumor. While it may be enticing to offer it to all patients who remotely meet indications, it has been proven that specific patient factors are imperative to achieving satisfactory clinical outcomes. While positive postoperative outcomes of MCT with OA or OA with intact cuff are, from my experience, generally very predictable, it is necessary to make sure patients are emotionally invested in their care. This is inherently a mechanical problem, and I believe it is crucial for a patient to perceive they have control over it. When it comes to other diagnoses, two studies performed on my patient population solidified my patient selection algorithm. The first study helped me identify the risk factors that can lead to patients having unexpectedly poor outcomes following RSA for MCTs without OA. Hartzler *et al.* performed a retrospective case-control analysis requiring a minimum follow-up of 2 years to identify the risk factors associated with poor outcomes after RSA. A logistic regression model revealed that neurologic dysfunction ($p = .006$), high preoperative Simple Shoulder Test (SST, $p = .03$) score, and age < 60 years ($p=.02$) were often associated with poor functional improvement (Hartzler *et al.,* 2015). It is crucial to mitigate patients' expectations as good outcomes are less predictable. In the second study, Lindbloom *et al.* aimed to identify which pathologies may lead to unpredictable outcomes following RSA. This comparative study analyzed the clinical outcomes of 699 patients at a minimum of 2 years who underwent RSA. Outcomes were compared based on changes in preoperative vs. postoperative scores in ASES, SST, VAS scores for function, range of motion, and health-related quality-of-life measures. While every pathology-based patient group reported on average significant improvement in measured outcomes, ultimately, it was seen that females with malunion had poorer forward flexion ($p < .05$), and any patient with fractures had poorer satisfaction ($p < .05$) ultimately. Interestingly, male patients who underwent RSA for MCT without OA had poorer patient satisfaction as well ($p < .05$; Lindbloom *et al.,* 2019). Lastly, when it comes to patients with MCT with preserved function, one needs to be cautious as postoperative outcomes tend to reflect an increase in dissatisfaction, loss of elevation ($p < .0001$; Boileau *et al.,* 2009) and increase in postoperative complications (Mulieri *et al.,* 2010).

Proper patient selection regarding indication, age, patient expectations, and clinical scoring tools undoubtedly have an integral role in satisfactory clinical outcomes.

Lesson 2: Glenosphere Positioning

Several aspects of glenosphere positioning have been found to yield a larger impingement-free abduction/adduction range of motion (ROM). Originally, Grammont believed that a medialized COR was imperative to increase the lever arm of the deltoid. Since then, many studies have argued for a more lateralized COR to secure the benefit of more impingement-free ROM at little to no loss of abduction. Some studies even found increased abduction forces with glenosphere COR lateralization (Tashjian *et al.,* 2015). At my lab, Gutierrez at el. used a computer model to simulate abduction/adduction motion with 5 factors: location and tilt angle of the glenosphere on the glenoid, implant size, COR offset, and humeral neck-shaft angle. Two variables appeared on the top of the hierarchy of surgical and implant-related factors – lateralized glenosphere and 135-degree neck-shaft angle

(Gutierrez *et al.,* 2008). With a follow-up study, Gutiérrez later concluded that for lateral and concentric glenospheres, inferior tilt provided the most even distribution of forces at the baseplate (Gutierrez *et al.,* 2011).

From my experience, the optimal glenosphere positioning should aim to maximize the function of the implant, confer appropriate soft tissue tension, avoid excessive arm lengthening, minimize bone resection, maximize the implant fixation while being technically reproducible. However, it is imperative to distinguish significant variability in the optimization of glenosphere position between normal and abnormal anatomy. While the former prioritizes the close reproduction of the centerline, the latter focuses on the technical aspects of the surgery and maximization of fixation.

Lesson 3: Glenoid Fixation

After its adoption in the US, research regarding complications of the RSA quickly identified the glenoid side as the main culprit (Frankle *et al.,* 2005). While patients reported a reduction in pain and improvement in functional outcomes as well as improvement in impingement-free range of motion, there were high rates of early mechanical failure (12%). This led me to re-evaluate the design and surgical technique with a focus on glenoid fixation. We identified three areas that, in my opinion, affect glenoid fixation the most: implant design, bone condition, and loading. Biomechanical studies showed that altered implant designs utilizing central compression screw coupled with 5 mm peripheral screws resulted in improved fixation due to the reduction in micromotion (Harman *et al.,* 2006; Gutierrez *et al.,* 2007). This was later confirmed in a prospective clinical study of RSA utilizing 5 mm peripheral locking screws for baseplate fixation and a lateralized COR (Cuff *et al.,* 2008). No radiographic evidence of the mechanical failure of the baseplate or scapular notching was noted in any of the patients (cohort of 112 patients), showing that the current advances in RSA allow for improved patient outcomes while minimizing early mechanical failure. When it comes to the condition of the bone, both quality and quantity must be equally considered. While pre-operative assessment of bone quality may be sometimes challenging, it is often advisable to take advantage of intraoperative haptic feedback and adjust bone preparation by "under-preparing" the osteoporotic bone and "over-preparing" sclerotic bone. For bone quantity consideration, the extent and pattern of glenoid bone loss may directly affect glenoid fixation and lead to post-operative muscular imbalance. In cases of severely abnormal anatomy, where the standard centerline can no longer be a feasible option, one has three options to maximize fixation and achieve reproducible reconstruction: alternative center line increased load sharing or both. To compare the outcomes of RSA using the anatomic or an alternative center line for glenoid baseplate fixation, we conducted a retrospective case-controlled study of patients who underwent RSA with a minimum follow-up of two years (Colley *et al.,* 2021). Patients treated via RSA with an anatomic center line vs. RSA with an alternative centerline were matched in a 3 : 1 fashion based on age, sex, and indication for surgery. The matched analysis (n = 66 for anatomic center line group, n = 22 for alternative center line group) found no differences in PROMs, including SST, ASES, SANE, and VAS scores. In addition, functional tasks of internal motion were not different between the two groups, and no radiologic evidence of glenoid loosening was found in either group (Colley *et al.,* 2021).

Lesson 4: Humeral Fixation

The majority of technological advancements in RSA in the last two decades successfully diminished early mechanical failures and complications that arise from glenoid fixation. The first generation of RSA stem I used had a modular junction and was exclusively cemented. While the performance of this design was adequate, an increase in RSA use resulted in a subsequent increase in RSA revisions which were more complex due to cemented stem. Furthermore, the expanded indications into the fracture and severe humeral bone loss made modular junction a potential design weakness. This prompted the introduction of a fully monolithic second-generation press-fitted stem. To evaluate the advancement in implant design and stem stability, a cohort comparison of 1st vs. 2nd generation humeral implant designs was conducted on my patients who underwent RSA n = 400 of whom received 1st generation cemented modular humeral implants and n = 231 of whom received 2nd generation monolithic, primarily uncemented implants (Gorman *et al.*, 2021). This study showed that both implants led to equivalent, improved clinical outcomes. However, the incidence of humeral loosening in the cemented group (3.6%) was greater than that of the uncemented group (0.4%, p = 0.01). Additionally, 4.0% of shoulders treated with the cemented technique were revised, while only 1.5% of shoulders treated with the press-fit technique were revised (p = 0.028) (Gorman *et al.*, 2021). When it comes to humeral stem revisions, especially when cement was used for the fixation of the primary stem, I learned that maintaining an intramedullary cement mantle may be of major advantage. In a retrospective review of all my patients who underwent revision of cemented RSA stem in the cement-within-cement technique, we first learned that an increase in cement volume during reimplantation and downsizing of the stem might lessen the chance of subsequent loosening and subsequent stem revisions (Gorman *et al.*, 2020). Interestingly, this clinical finding significantly differed from my intraoperative assessment of stem stability, and as a result, we performed a biomechanical investigation into the matter. A 12 mm and 6 mm stem cemented within the previous cement mantle were tested in the biomechanical sawbones model for stability by applying torque for 1.000 cycles from 2.5 N-m to 17.5 N-m. Results showed superior stability of the larger stem (p < .001; Gorman 2020). Hence, my original recommendation of downsizing the stem has been corrected.

Lesson 5: Soft-tissue Management and Tensioning

Soft tissue management and tensioning are considered on a case-by-case basis when evaluating patients for RSA, both preoperatively and intraoperatively. For me, the principal goal of soft-tissue management is multi-faceted and includes re-tensioning of the cuff, improvements in range of motion, joint stabilization, preservation of shoulder contour, and improvements in impingement arc. Effective tensioning of the cuff muscles after RSA can be achieved through lateralization of either glenosphere, stem, or both. Henninger *et al.* directly compared the performance of two RSA systems with opposing magnitude of medialization/lateralization (Henninger *et al.*, 2014). This cadaveric study tested seven pairs of shoulders on a biomechanical simulator and quantified changes in COR, the position of the humerus, passive and active ROM, and force required to abduct the ar, before and after implantation of an RSA design of interest. In both implants, COR was shifted inferomedially compared to the native shoulder, however medial shifts were greater in the medialized implant group (Aequalis, p < 0.037). All humeri were shifted inferiorly compared to native, with those in the medialized implant group also shifting medially (p < 0.001). Both implants reduced adduction of the shoulder, but the lateralized implant group did this to a lesser degree (DJO RSP, p = 0.046). Additionally, both implants reduced the force required to initiate abduction compared to native, however, the lateralized implant group required less force compared to the medialized implant group (p = 0.022). There were no differences in changes of internal rotation, external rotation, or peak passive abduction between the two systems. Further confirmation of the positive effect of the lateralized implant on the cuff re-tensioning was reported by (Gorman *et al.*, 2013). Based on the cadaver-based computer model, the authors concluded that cuff muscle tension was preserved with the lateralized RSA design. What about stability? In the biomechanical bone surrogate study, Gutierrez *et al.* aimed to evaluate the hierarchy of stabilizing factors when using RSA with different levels of lateralization. The study concluded that the joint compressive forces generated by rotator cuff muscle and deltoid is the principal stabilizing factor in RSA design (Gutierrez *et al.*, 2007). Although implant lateralization (glenosphere and stem) seems to have a positive effect on cuff muscle tension, and this increase translates into deltoid lengthening, there are inherent risks associated with excessive distalization, namely, iatrogenic nerve injury and scapular spine fractures (Ladermann *et al.*, 2012; Haidamous *et al.*, 2020).

Conclusion

As in other developments in medicine, research in the field of RSA is ever-changing with advances every year. It is essential to build upon the knowledge of those with the most experience to advance the field of RSA further. In this paper, the understandings of a surgeon with 20 years of experience in RSA are distilled down to 5 key principles. In conclusion, to increase the chances of a successful RSA procedure, a surgeon should emphasize picking the right patient, placing an implant in an optimum position, ensuring adequate glenoid and humeral fixation, and correctly balancing soft tissues.

REFERENCES

Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. (2009) *'Reverse total shoulder arthroplasty after failed rotator cuff surgery'.* J Shoulder Elbow Surg.18(4): 600–606.

Colley R, Polisetty TS, Levy JC. (2021) *'Midterm outcomes of reverse shoulder arthroplasty using the alternative center line for glenoid baseplate fixation: a case-controlled study'.* J Shoulder Elbow Surg.30(2): 298–305.

Cuff D, Pupello D, Virani N, Levy J, Frankle M. (2008) *'Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency'.* J Bone Joint Surg Am. 90(6):1244–1251.

Flatow EL, Harrison AK. (2011) *'A history of reverse total shoulder arthroplasty'*. Clin Orthop Relat Res.469(9): 2432–2439.

Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. (2005) *'The Reverse Shoulder Prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients'.* J Bone Joint Surg Am.87(8): 1697–1705.

Gorman RA 2nd, Christmas KN, Simon P, Hess AV 2nd, Brewley EE Jr, Mighell MA, Frankle MA. (2020) *'Optimizing humeral stem fixation in revision reverse shoulder arthroplasty with the cement-within-cement technique'.* J Shoulder Elbow Surg.29(7S): S9–S16.

Gorman, RA 2nd, Diaz AM, Simon P, Christmas KN, Mighell MA, Frankle MA. (2021) *'Optimizing humeral stem fixation in revision shoulder arthroplasty with the cement-within-cement technique: A biomechanical evaluation. Journal of shoulder and elbow surgery'.* Seminars in Arthroplasty.vol. 30, 3 (2020): 210–216.

Gorman RA 2nd, Christmas KN, Simon P, Mighell MA, Frankle MA. (2021) *'A cohort comparison of humeral implant designs in reverse shoulder arthroplasty: does implant design lead to lower rates of complications and revision?;* J Shoulder Elbow Surg.30(4): 850–857.

Grammont P, Trouilloud P, Laffay J, Deries X. (1987) *'Etude et realisation d'une nouvelle prothese d'epaule.'* Rhumatologie 39: 407–418.

Greiner S, Schmidt C, König C, Perka C, Herrmann S. (2013) *'Lateralized reverse shoulder arthroplasty maintains rotational function of the remaining rotator cuff.'* Clin Orthop Relat Res.471(3): 940–946.

Gutiérrez S, Walker M, Willis M, Pupello DR, Frankle MA. (2011) *'Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse* *shoulder arthroplasty.'* J Shoulder Elbow Surg.20(5): 732–739.

Gutiérrez S, Comiskey CA 4th, Luo ZP, Pupello DR, Frankle MA. (2008) *'Range of impingement-free abduction and adduction deficit after reverse shoulder arthroplasty. Hierarchy of surgical and implant-design-related factors'*. J Bone Joint Surg Am.90(12): 2606–2615.

Gutiérrez S, Keller TS, Levy JC, Lee WE 3rd, Luo ZP. (2008) *'Hierarchy of stability factors in reverse shoulder arthroplasty'*. Clin Orthop Relat Res.466(3): 670–676.

Haidamous G, Lädermann A, Frankle MA, Gorman RA 2nd, Denard PJ. (2020) *'The risk of postoperative scapular spine fracture following reverse shoulder arthroplasty is increased with an onlay humeral stem'*. J Shoulder Elbow Surg.29(12): 2556–2563.

Harman M, Frankle M, Vasey M, Banks S. (2005) *'Initial glenoid component fixation in "reverse" total shoulder arthroplasty: a biomechanical evaluation'*. J Shoulder Elbow Surg.14(1 Suppl S): 162S–167S.

Hartzler RU, Steen BM, Hussey MM, Cusick MC, Cottrell BJ, Clark RE, Frankle MA. (2015) *'Reverse shoulder arthroplasty for massive rotator cuff tear: risk factors for poor functional improvement'*. J Shoulder Elbow Surg.24(11): 1698–1706.

Henninger HB, King FK, Tashjian RZ, Burks RT. (2014) *'Biomechanical comparison of reverse total shoulder arthroplasty systems in soft tissue-constrained shoulders'*. J Shoulder Elbow Surg.23(5): e108–117.

Lädermann A, Walch G, Lubbeke A, Drake GN, Melis B, Bacle G, Collin P, Edwards TB, Sirveaux F. (2012) *'Influence of arm lengthening in reverse shoulder arthroplasty'*. J Shoulder Elbow Surg.21(3): 336–341.

Lädermann A, Walch G, Lubbeke A, Drake GN, Melis B, Bacle G, Collin P, Edwards TB, Sirveaux F. (2012) *'Influence of arm lengthening in reverse shoulder arthroplasty.'* J Shoulder Elbow Surg.21(3): 336–341.

Mulieri P, Dunning P, Klein S, Pupello D, Frankle M. (2010) *'Reverse shoulder arthroplasty for the treatment of irreparable rotator cuff tear without glenohumeral arthritis'*. J Bone Joint Surg Am.92(15): 2544–2556.

Ryan Danny *'Indications for Reverse Shoulder Arthroplasty. Shoulder Arthroplasty'*. Springer, Cham, 2020.

Schairer WW, Nwachukwu BU, Lyman S, Craig EV, Gulotta LV. (2015) *'National utilization of reverse total shoulder arthroplasty in the United States'*. J Shoulder Elbow Surg.24(1): 91–97.

Tashjian RZ, Burks RT, Zhang Y, Henninger HB. (2015) *'Reverse total shoulder arthroplasty: a biomechanical evaluation of humeral and glenosphere hardware configuration.'* J Shoulder Elbow Surg.24(3): e68–77.

Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. (2007) *'Reverse total shoulder arthroplasty: a review of results according to etiology'*. J Bone Joint Surg Am. 89(7): 1476–1485.

Werthel JD, Walch G, Vegehan E, Deransart P, Sanchez-Sotelo J, Valenti P. (2019) *'Lateralization in reverse shoulder arthroplasty: a descriptive analysis of different implants in current practice'*. Int Orthop.43(10): 2349–2360.

Westermann RW, Pugely AJ, Martin CT, Gao Y, Wolf BR, Hettrich CM. (2015) *'Reverse Shoulder Arthroplasty in the United States: A Comparison of National Volume, Patient Demographics, Complications, and Surgical Indications'*. Iowa Orthop J.35: 1–7.