Review article

Going forward with reverse shoulder arthroplasty

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ABSTRACT

Rotator cuff is a vital structure of glenohumeral joint, the dysfunction of which leads to debilitating pain and restricted movement. Arthroplasty using unconstrained anatomical prosthesis for treating these conditions have not been successful in the past. Reverse Shoulder Arthroplasty (RSA) is a novel technique specifically designed to address end stage glenohumeral arthritis in rotator cuff deficient joint. Short and mid-term studies have demonstrated a significant improvement in pain and range of motion of the shoulder joint. However there is a very high complication rate in comparison to total and hemiarthroplasty of shoulder joint. Over the years, there has been a steady increase in RSAs performed, both in volume and the indications for its use. This article discusses the biomechanical aspects, indications and critically reviews the clinical outcome following Reverse Shoulder Arthroplasty.

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1. Introduction

Cuff Tear Arthropathy (CTA) was first described by Neer et al. to describe the pathoanatomy of glenohumeral joint secondary to deficient rotator cuff¹, which led to proximal migration of humeral head and degenerative changes in the glenohumeral joint.² Total shoulder Arthroplasty (TSA) was offered as surgical treatment for this condition, though it later became obvious that a deficient rotator cuff caused excessive and eccentric loading of the glenoid component along with superior migration of humeral component, which eventually led to its failure. Subsequently, Neer and others advocated hemiarthroplasty (HA) as the preferred management option.^{3–5} However, these treatment options had unpredictable and poor outcomes as demonstrated by various authors.^{5,6}

Reverse polarity shoulder arthroplasty was therefore developed to overcome these shortcomings but the initial designs, constrained or semiconstrained had high failure rates and were soon discontinued.^{7,8} Amongst various designs, reverse polarity prosthesis, first introduced by Paul Grammont et al.⁹ proved more successful and the most commonly used prostheses. Short-term and mid-term clinical studies have shown good clinical outcomes however long-term follow up studies are still not available. Despite the high complication rate of Reverse Shoulder Arthroplasty (RSA), but lacking a better alternative, many authors have expanded the indications for RSA and used it in conditions such as severe

proximal humeral fractures, failed arthroplasty, proximal humeral tumours etc.

In the wake of many such studies demonstrating encouraging short term and mid-term results with RSA, we aim to revisit various biomechanical and functional outcome aspects related to RSA for better understanding of this promising but technically demanding procedure.

2. Biomechanics and design

2.1. Biomechanics of Cuff Tear Arthropathy

The stability of the normal shoulder joint is based on the concept of concavity-compression¹⁰ as illustrated by the example of a ball sitting in a concave area of the table (Fig. 1). For a given compressive load on the ball, the greater the depth of the concavity, the greater the displacing force must be to dislodge the ball from its position. Greater compressive load is needed to balance a shoulder joint which has a shallow glenoid concavity. The normal rotator cuff provides this compressive load to the humeral head, the absence of which leads to instability.^{2,11} With the aid of the rotator cuff as dynamic stabilisers, the deltoid is able to elevate the shoulder against the glenoid as a fulcrum. In the absence of these stabilisers the humeral head migrates superiorly and impinges against the under surface of acromion, restricting the range of movement and causing pain. (Fig. 2) The basis of reverse shoulder arthroplasty is to create a fixed fulcrum at the glenoid against which the arm can be rotated by the deltoid, which cannot be addressed by unconstrained anatomic design prosthesis, leading to their failure in CTA.

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Fig. 1. Concept of concavity-compression in a normal shoulder joint.

Fig. 2. Cuff Tear Arthropathy pathoanatomy-schematic diagram.

2.2. Current design

The prostheses currently used are based on Grammont's reverse polarity prosthesis, the key principles being:

1. Fixed centre of rotation, distalised and medialised in relation to the glenoid surface
2. Intrinsic stability
3. Effective lever arm of deltoid to initiate movement
4. Semi-constrained design by large glenosphere and small humeral cup^{12,13}

The centre of rotation of a native shoulder joint is variable and lies close to the centre of the humeral head.¹⁴ RSA on the other hand creates a new and fixed centre of rotation located at the bone-implant interface which increases the inherent stability of the prosthesis. (Fig. 3) The medialisation helps in converting shear forces into compressive forces at the bone-implant interface,¹⁵ but can result in scapular notching, tuberosity impingement, decreased movements and loss of deltoid contour.¹¹ (Fig. 4) To overcome scapular notching various design strategies that were utilised include eccentric glenosphere position, inferior tilt of the glenoid component, increased lateral offset and decreased neck shaft angle of the humeral component.¹⁶

Eccentric glenosphere positioning resulting in inferior overhang of the glenosphere, leads to the creation of a space between the scapular neck and the glenosphere. This decreases the incidence of scapular notching and reduces impingement of the humeral tuberosity against the acromion resulting in increased range of motion.¹⁷ (Fig. 5)

Inferior inclination of the glenoid component has shown contradictory results. Cadaveric studies¹⁶ demonstrated increased

Fig. 3. Biomechanics of Reverse shoulder Arthroplasty- schematic diagram.

Fig. 4. Scapular Notching.

impingement-free range of movements following which has not been validated by clinical studies.¹⁸ (Fig. 5)

Lateralisation of the medialised COR can increase the range of motion but can also increase stress at the bone implant interface.¹⁹ (Fig. 6) To harness the advantages of lateralisation and to decrease the stresses on the glenoid bone-implant interface, Boileau et al.²⁰ came forward with Bony Increased-Offset Reverse Shoulder Arthroplasty (BIO RSA) which provides a large glenoid hemisphere and deep concave humeral cup complementing each other leading

Fig. 5. Eccentric Glenosphere and inferior inclination- schematic diagram.

Fig. 6. Lateralisation of the Center of rotation- schematic diagram.

to a stable and conforming arc of motion A bone graft is inseted between the glenoid component and reamed glenoid surface.

2.3. Deltoid function

Medialisation of COR increases the moment arm of deltoid by 20–42%, recruiting additional fibres of deltoid aiding in abduction.²¹ Distalisation of COR also increases the resting tone of Deltoid muscle improving efficacy by 30%.^{13,22} (Fig. 3)

Table 1

Indication and relative frequencies.

Indications	National Joint Registry (United Kingdom) [28] 2016 annual report	Australian Joint registry [29] 2016 annual report	United States of America [30], 2015
Cuff tear arthropathy (including massive rotator cuff tear)	50.3%	34.1%	14.38%
Osteoarthritis	19.5%	45.6%	43.67%
Fracture/trauma sequele	7.0%	14.6%	12.62%
Avascular necrosis	0.7%	1.1%	0.98%
Inflammatory arthropathy (including Rheumatoid arthritis)	2.6%	2.6%	1%
Tumor	–	0.7%	–
Instability	–	1.2%	–
Other causes	1.6%	–	14.15%

2.4. Limitations of RSA prosthesis design

The RSA design has created improved flexion abduction motion at the expense of axial rotation of the arm. Because of alteration of native anatomy by this non-anatomic RSA prosthesis, especially by medialising COR, the deltoid's anterior and posterior fibres lose their axial rotation function and instead behave as flexor-abductors and extensor-adductors respectively.²³ Because of this medialisation of COR, the rotational moment arms of subscapularis and teres minor are negatively affected, compromising the loss of axial rotation even further.²⁴ Latissimus dorsi transfer during the primary RSA surgery has been shown to be effective in restoring external rotation in these patients.²⁵

3. Indications and Contra-Indications

3.1. Indications

The traditional indication has been cuff tear arthropathy (CTA).²⁶ The success of reverse shoulder arthroplasty in rotator cuff arthropathy gradually led to expansion of its use to other situations in which unconstrained prostheses such as hemiarthroplasty or total shoulder arthroplasty showed poor results. Currently, all forms of end-stage shoulder arthritis with concomitant rotator cuff tear or loss of function are amenable to reverse shoulder arthroplasty.²⁷

The data collected from two leading joint registries from the United Kingdom(UK) and Australia, and the United States Nationwide Inpatient Sample dataset demonstrate the frequency

of use for various indications. (Table 1) Whereas in the UK, the most common indication for RSA remains CTA, in Australia and the US, the most common indication is osteoarthritis. Fractures of the proximal humerus and its sequelae rank third as per all three databases. Emerging indications include shoulder dysplasia³¹, chronic glenohumeral dislocation³², glenohumeral arthritis with severe glenoid bone loss³³ and revision arthroplasty^{34–36}.

Contraindication: One of the important part of RSA is the function of deltoid. Any condition that impairs its function is a contraindication for this surgery including Axillary nerve palsy. Infection is an absolute contraindication. The other relative contraindications are inadequate glenoid bone stock which precludes stable implantation of the glenoid component and neuropathic joints.

4. Outcomes

Many authors have published their work on RSA done for varying etiologies including CTA, where rotator cuff deficiency or dysfunction preclude use of other modalities such as TSA or HA. Consequently, the survivorship and functional outcome vary according to etiology. Some of the authors have published their work involving RSA done for multiple etiologies in a single publication and hence comparisons with other studies is not straightforward.

A seminal study published by Wall B et al.²⁷ reported their results following RSA in 191 shoulders. RSA was performed for CTA in 30.8%, revision arthroplasty in 22.5%, massive rotator cuff tear in 17.1% and post-traumatic arthritis in 13.8%. At an average 40 months follow up they concluded that RSA yielded good functional outcome in all groups. However patients with post traumatic arthritis and revision arthroplasty showed less improvement and higher complication rate when compared to those done for CTA.

4.1. Cuff tear arthroplasty

Favard et al.³⁷ showed a survivorship of 89% at 10 years follow up with removal of prosthesis or conversion to hemiarthroplasty as end point. They reviewed 527 shoulders retrospectively of which 464 had a minimum 2 years follow up and 148 had a minimum 5 years follow up with an average of 7.5 years in total. They had a complication rate of 21% and 50% incidence of scapular notching. Deterioration in functional results were noted after 8th year.

Guery J et al.,³⁸ in their multicentric study involving 80 shoulders with RSA followed up for a minimum of 5 years, showed an overall survival rate of 91% with implant revision as the end point. The study also involved patients with other etiologies such as Rheumatoid arthritis, fracture and previous anatomic prosthesis. The survival rate for these indications were 77% at 9 years in comparison to 95% for CTA.

Both Favard et al. and Guery et al. noted better outcomes in RSA done for CTA and massive rotator cuff tear but deteriorating results after 8 and 6 years respectively. They both advise caution on the use of RSA in younger patients.

In terms of functional outcome, Naveed et al.³⁹ demonstrated excellent results in a group of 43 patients (50 shoulders) who underwent RSA for CTA and massive cuff tear at a mean follow up period of 39 months. ASES (American Shoulder and elbow score) showed improvement from an average of 19 preoperatively to 65 post-operatively along with improvement in elevation from 55° to 105° at final follow up.

The Charts 1 and 2 summarise similar studies done over the past decade, arranged in chronological order, with revision rate in Chart 1 and functional outcome measure in Chart 2.

Chart 1. RSA done for CTA and massive rotator cuff tear- follow up time in months and revision rate [26,34,37,74–78].

Chart 2. RSA for CTA and massive rotator cuff tear: functional outcome measures Constant-Murley scores [26,34,37,74–78].

4.2. Proximal humeral fracture and sequelae

Neer had advocated hemiarthroplasty for irreparable proximal humerus fractures⁴⁰ but subsequent studies showed poor outcome in these patients with proximal migration of humeral head along with pain and restricted range of motion.^{41,42}

Brorson et al.⁴³ showed a survival rate of 96% at 5 years for RSA done for proximal humerus fractures in a group of 565 RSAs from data collected from Nordic registry. The most common reason for revision was infection. RSA and operation in young patients had higher risk of infection in comparison to HA done for same reason.

Wolfensperger et al.⁴⁴ in their prospective study done on 33 patients who underwent RSA for proximal humeral fractures showed good functional results, pain control and restored quality of life in patients older than 70 years at the end of one year.

Bufquin et al.⁴⁵ also demonstrated improved clinical outcome at mean follow up of 22 years in 43 patients. This group also had displacement of tuberosities in 53% and scapular notching in 25% of patients as complication.

Most other studies reveal similar results however caution on performing RSA on patients younger than 70 years.

4.3. Salvage procedure for failed arthroplasty

RSA has emerged as a suitable option in unconstrained arthroplasty of shoulder (TSA, HA) with rotator cuff deficiency.

Levy et al.³⁶ demonstrated an average improvement in ASES score from 22.3 preoperatively to 52.1 following RSA for failed hemiarthroplasty procedure done for fracture proximal humerus, in a group of 29 patients of mean age 69 years at 35 months of average follow up. In this group there was a complication rate of 28%.

A similar study by Gholke et al.⁴⁶ on 34 patients who underwent revision to RSA for failed fracture hemiarthroplasties at 59 months follow up showed an average improvement in their Constant score from 17.5% pre-operatively to 63% postoperatively. All patients reported reduced pain, and range of motion improved from 48° to 125°. There were 8 complications in total.

Although multiple studies have confirmed improved functional outcome and pain relief following salvage procedure with RSA for failed total or hemiarthroplasty, revision to RSA is still less predictable and has higher complication rates compared to primary RSA for CTA or massive cuff tear arthropathy.^{34,38, 27, 47}

4.4. Inflammatory arthropathy

Previous authors had noted poor results in Rheumatoid patients⁴⁸, but recent systematic reviews showed good short to mid-term results without higher complication rates as compared to using RSA in CTA.^{49,50} Short and mid-term results have shown a remarkable functional improvement with good survival rate, however, long term studies are necessary to establish the efficacy of RSA.

5. Complications

RSA provides improved function and pain relief however it is prone to complications. The reported rate of complications of RSA is higher than that for TSA.⁵¹ A complication rate of up to 13% is reported for primary RSA and 37% for revision RSA.⁵²

5.1. Instability

The most common complication is instability which is about 4%^{53,54} and almost double for revision RSA.⁵⁴ Tumour surgery, arthropathy for instability and fracture sequelae have been shown to have highest risk for instability.^{55,56, 57} It has also been noted that instability manifests within the first six months of surgery.⁵⁸ Possible reasons include poor deltoid tension, malposition of components, subscapularis insufficiency and poor soft tissues.^{59,60, 61} Some authors have emphasized the importance of subscapularis repair or condition in improving stability of the prosthetic joint.^{27,57}

5.2. Infection

Infection rates of up to 15% have been noted in published literature^{27,37,54} with *Propionibacterium acnes* being the commonest pathogen isolated from infected RSA.⁶² The risk of infection is much higher than that for TSA; some studies report up to six times higher.⁶³ Various reasons have been cited including increased surface area of the implant, greater dead space, longer operation time and patient factors such as an older treatment group with significant medical conditions.^{43,53}

5.3. Scapular notching

Notching is the result of inferior scapular neck erosion because of humeral component impingement⁶⁴, the incidence reported in literature ranging from 0% to 96%.^{26,54, 65, 66} Reasons cited include use of antero-superior approach, superior tilting of glenoid, and high position of glenoid component.⁶⁵ Published literature show mixed results as to the correlation between notching and clinical outcome. Sirveaux Fet al.²⁶ and Simovitch RW et al.⁶⁴ have shown poor outcome because of scapular notching but Levine C et al. noted no correlation.⁶⁵

5.4. Other complications

Nerve Palsy, particularly of the axillary nerve has been found to be a potential complication of the RSA, mainly related to the extent of lengthening of the arm.⁶⁷ Most of these are subclinical and undergo spontaneous recovery.⁶⁸ Ladermann A et al. in their review noted that lengthening of arm more than 2 cm carries a higher risk of nerve injury.⁶⁹ The suprascapular nerve and artery may be at risk at the spinoglenoid notch especially when drilling the posterior screw.

Like any other arthroplasty prosthesis, loosening of one or more components with time have been noted with RSA. Melis et al. noted radiologic loosening of humeral components in 20% of cemented stems and 8% of uncemented stems at 8 years with uncertain long term clinical significance.⁷⁰ Incidence of glenoid component loosening has been noted to be higher in lateralised designs because of increased stresses at the bone implant interface, leading to increased risk of revision surgery.⁷¹

Acromial insufficiency arises mainly because of impingement of the humeral head against the acromion process, leading to fracture of acromion, and pseudoarthrosis of scapular spine. The estimated incidence of this complication is about 9%.⁷² These lead to poorer clinical outcomes especially the forward elevation.⁷³

6. Summary

There has been a recent increase in the number of RSAs performed worldwide, comprising up to 50%³⁰ of all arthroplasty procedures performed for shoulder. This has been noted in the leading joint registries and national databases.^{28,29} Even though the long term studies are awaited, RSA is increasingly being accepted as a reliable option for a range of pathologies for which there is no suitable alternative. The available evidence indicates that RSA is most successful in CTA, resulting in predictable improved range of motion and relief of pain, which has been noted to deteriorate over time. RSA is associated with a high complication rate and revision surgery of failed RSA has an unpredictable outcome. The current trend certainly suggests that Reverse Shoulder Arthroplasty is the way forward for painful conditions of shoulder with deficient rotator cuff. However, RSA should not be considered a panacea for all rotator cuff deficient conditions and hence recommend its judicious use in carefully selected patients.

Research is also needed in improving the design of the prosthesis to decrease the complication rate.

Conflict of interest

The authors have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

- Neer II CSII, Craig EV, Fukuda H. Cuff tear arthropathy. *J Bone Joint Surg.* 1983;65-A:1232–1244.
- Ecklund KJ, Lee TQ, Tibone J, Gupta R. Rotator cuff tear arthropathy. *J Am Acad Orthop Surg.* 2007;15:340–349.
- Neer 2nd CS2nd, Watson K, Stanton FJ. Recent experience in total shoulder replacement. *J Bone Joint Surg Am.* 1982;64:319–337.
- Williams Jr GRJr, Rockwood Jr CAJr. Hemiarthroplasty in rotator cuff-deficient shoulders. *J Shoulder Elbow Surg.* 1996;5:362–367.
- Zuckerman JD, Scott AJ, Gallagher MA. Hemiarthroplasty for cuff tear arthropathy. *J Shoulder Elbow Surg.* 2000;9:169–172.
- Pollock RG, Deliz ED, McIlveen SJ, Flatow EL, Bigliani LU. Prosthetic replacement in rotator cuff deficient shoulders. *J Shoulder Elbow Surg.* 1992;1:173–186.
- Brostrom LA, Wallensten R, Olsson E, Anderson D. The Kessel prosthesis in total shoulder arthroplasty. A five-year experience. *Clin Orthop Relat Res.* 1992; (277):155–160.
- Fenlin Jr JMJr. Semi-constrained prosthesis for the rotator cuff deficient patient. *Orthop Trans.* 1985;9:55.
- Grammont PM, Baulot E. Delta Shoulder prosthesis for rotator cuff rupture. *Orthopaedics.* 1993;16:65–68.
- Matsen F, Lippitt S. Principles of glenohumeral stability. In: Matsen F, Lippitt S, DeBartolo S, eds. *Shoulder Surgery: Principles and Procedures*. Philadelphia: WB Saunders; 2004:83.
- Boileau P, Watkinson DJ, Hatzidakis A, Balg F. Grammont reverse prosthesis: design, rationale and biomechanics. *J Shoulder Elbow Surg.* 2005;14(suppl S):147S–161S.
- Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. Reverse total shoulder arthroplasty after failed rotator cuff surgery. *J Shoulder Elbow Surg.* 2009;18:600–606.
- Grammont P, Trouilloud P, Laffay J, Deries X. Etude et réalisation d'une nouvelle prosthèse d'épaule. *Rheumatologie.* 1987;39:407–418.
- Fischer L, Carret J, Gonon G, Dimnet J. Etude cinématique des mouvements de l'articulation scapulo-humérale. *Rev Chir Orthop Reparatrice Appar Mot.* 1977;63:108–115.
- Kontaxis A, Johnson GR. The biomechanics of reverse anatomy shoulder replacement—a modelling study. *Clin Biomech (Bristol, Avon).* 2009;24:254–260.
- Nyffeler RW, Werner CM, Gerber C. Biomechanical relevance of glenoid component positioning in the reverse Delta III total shoulder prosthesis. *J Shoulder Elbow Surg.* 2005;14(5):524–528.
- Chou J, Malak SF, Anderson IA, Astley T, Poon PC. Biomechanical evaluation of different designs of glenospheres in the SMR reverse total shoulder prosthesis: range of motion and risk of scapular notching. *J Shoulder Elbow Surg.* 2009;18:354–359.
- Edwards TB, Trappey GJ, Riley C, O'Connor DP, Elkousy HA, Gartsman GM. Inferior tilt of the glenoid component does not decrease scapular notching in reverse shoulder arthroplasty: results of a prospective randomized study. *J Shoulder Elbow Surg.* 2012;21:641–646.
- Harman M, Frankle M, Vasey M, Banks S. Initial glenoid component fixation in reverse total shoulder arthroplasty: a biomechanical evaluation. *J Shoulder Elbow Surg.* 2005;14(suppl S):162S–167S.
- Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid function. *Clin Orthop Relat Res.* 2011;469:2558–2567.
- Terrier A, Reist A, Merlini F, Farron A. Simulated joint and muscle forces in reversed and anatomic shoulder prostheses. *J Bone Joint Surg Br.* 2008;90:751–756.
- Henninger HB, Barg A, Anderson AE, Bachus KN, Tashjian RZ, Burks RT. Effect of deltoid tension and humeral version in reverse total shoulder arthroplasty: a biomechanical study. *J Shoulder Elbow Surg.* 2012;21:1128–1135.
- Ackland DC, Roshan-Zamir S, Richardson M, Pandey MG. Moment arms of the shoulder musculature after reverse total shoulder arthroplasty. *J Bone Joint Surg Am.* 2010;92:1221–1230.
- Herrmann S, König C, Heller M, Perka C, Greiner S. Reverse shoulder arthroplasty leads to significant biomechanical changes in the remaining rotator cuff. *J Orthop Surg Res.* 2011;6:42.
- Favre P, Loeb Md Helmy N, Gerber C. Latissimus dorsi transfer to restore external rotation with reverse shoulder arthroplasty: a biomechanical study. *J Shoulder Elbow Surg.* 2008;17:650–658.
- Sirveaux F, Favard L, Oudet D, et al. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. *J Bone Joint Surg Br.* 2004;86:388–395.
- Wall B, Nove-Jossander L, O'Connor DP, et al. Reverse total shoulder arthroplasty: a review of results according to etiology. *J Bone Joint Surg Am.* 2007;89:1476–1485.
- National Joint Registry for England, Wales and Northern Ireland. 13th Annual Report. [Accessed on 10th September 2017] <http://www.njrreports.org.uk/Portals/0/PDFdownloads/NJR%2013th%20Annual%20Report%202016.pdf>.
- Australian Orthopaedic Association National Joint Replacement Registry. Annual Report. [Accessed on 10th September 2017] <https://aoanjjr.sahmri.com/documents/10180/275066/Hip%2C%20Knee%20%26%20Shoulder%20Arthroplasty>.
- Westermann RW, Pugely AJ, Martin CT, Gao Y, Wolf BR, Hettrich CM. Reverse shoulder arthroplasty in the United States: a comparison of national volume, patient demographics, complications, and surgical indications. *Iowa Orthop J.* 2015;35:1.
- Edwards TB, Boulahia A, Kempf JF, Boileau P, Nemoz C, Walch G. Shoulder arthroplasty in patients with osteoarthritis and dysplastic glenoid morphology. *J Shoulder Elbow Surg.* 2004;13(1):1–4.
- Sahajpal DT, Zuckerman JD. Chronic glenohumeral dislocation. *J Am Acad Orthop Surg.* 2008;16(7):385–398.
- Martin TC, Iannotti JP. Reverse total shoulder arthroplasty for acute fractures and failed management after proximal humeral fractures. *Orthop Clin North Am.* 2008;39(4):451–457 [vi].
- Boileau P, Watkinson D, Hatzidakis AM, Hovorka I. Neer Award 2005: The Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. *J Shoulder Elbow Surg.* 2006;15(5):527–540.
- Holcomb JO, Cuff D, Petersen SA, Pupello DR, Frankle MA. Revision reverse shoulder arthroplasty for glenoid baseplate failure after primary reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2009;18(5):717–723.
- Levy JC, Virani N, Pupello D, Frankle M. Use of the reverse shoulder prosthesis for the treatment of failed hemiarthroplasty in patients with glenohumeral arthritis and rotator cuff deficiency. *J Bone Joint Surg Br.* 2007;89(2):189–195.
- Favard L, Levigne C, Nerot C, Gerber C, De Wilde L, Mole D. Reverse prostheses in arthroplasties with cuff tear: are survivorship and function maintained over time? *Clin Orthop Relat Res.* 2011;469(9):2469–2475.
- Guery J, Favard L, Sirveaux F, Oudet D, Mole D, Walch G. Reverse total shoulder arthroplasty: survivorship analysis of eighty replacements followed for five to ten years. *JBS.* 2006;88(August (8)):1742–1747.
- Naveed MA, Kitson J, Bunker TD. The Delta III reverse shoulder replacement for cuff tear arthroplasty. *Bone Joint J.* 2011;93(January (1)):57–61.
- Neer II Charles SII. Displaced proximal humeral fractures: Part II. Treatment of Three-part and Four-part Displacement. *JBS.* 1970;52(September (6)):1090–1103.
- Antuna SA, Sperling JW, Cofield RH. Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up. *J Shoulder Elbow Surg.* 2008;17(2):202–209.
- Noyes MP, Kleinhens B, Markert RJ, Crosby LA. Functional and radiographic long-term outcomes of hemiarthroplasty for proximal humeral fractures. *J Shoulder Elbow Surg.* 2011;20(3):372–377.
- Brorson S, Salomonsson B, Jensen SL, Fenstad AM, Demir Y, Rasmussen JV. Revision after shoulder replacement for acute fracture of the proximal humerus: a Nordic registry-based study of 6,756 cases. *Acta Orthop.* 2017;88(4):446–450.10.1080/17453674.2017.1307032.
- Wolfensperger F, Grüniger P, Dietrich M, et al. Reverse shoulder arthroplasty for complex fractures of the proximal humerus in elderly patients: impact on the level of independency, early function, and pain medication. *J Shoulder Elbow Surg.* 2017;.
- Bufquin T, Hersan A, Hubert L, Massin P. Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly. *Bone Joint J.* 2007;89(April (4)):516–520.
- Gohlke F, Rolf O. Revision of failed fracture hemiarthroplasties to reverse total shoulder prosthesis through the transhumeral approach: method incorporating a pectoralis-major-pedicled bone window. *Oper Orthop Traumatol.* 2007;19(June (2)):185–208.
- Austin L, Zmistowski B, Chang ES, Williams G R Jr. Is reverse shoulder arthroplasty a reasonable alternative for revision arthroplasty? *Clin Orthop.* 2011;469:2531–2537.
- Boileau P, Sinnerton RJ, Chuinard C, Walch G. Arthroplasty of the shoulder. *Bone Joint J.* 2006;88(May (5)):562–575.
- Gee EC, Hanson EK, Saithna A. Reverse shoulder arthroplasty in rheumatoid arthritis: a systematic review. *Open Orthop J.* 2015;9:237.
- Cho CH, Kim DH, Song KS. Reverse shoulder arthroplasty in patients with rheumatoid arthritis: a systematic review. *Clin Orthop Surg.* 2017;9(September (3)):325–331.
- Barco R, Savvidou OD, Sperling JW, Sanchez-Sotelo J, Cofield RH. Complications in reverse shoulder arthroplasty. *EFORT Open Rev.* 2016;1(March (3)):72–80.

52. Wall B, Walch G. Reverse shoulder arthroplasty for the treatment of proximal humeral fractures. *Hand Clin.* 2007;23(November (4)):425–430.
53. Cheung E, Willis M, Walker M, Clark R, Frankle MA. Complications of reverse total shoulder arthroplasty. *J Am Acad Orthop Surg.* 2012;19:439–449.
54. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations and revisions in reverse total shoulder arthroplasty: a systematic review. *J Shoulder Elbow Surg.* 2011;20:146–157.
55. Raiss P, Edwards TB, da Silva MR, Bruckner T, Loew M, Walch G. Reverse shoulder arthroplasty for the treatment of nonunions of the surgical neck of the proximal part of the humerus (type-3 fracture sequelae). *JBJS.* 2014;96(December (24)):2070–2076.
56. De Wilde LF, Plasschaert FS, Audenaert EA, Verdonk RC. Functional recovery after a reverse prosthesis for reconstruction of the proximal humerus in tumor surgery. *Clin Orthop Related Res.* 2005;430(January):156–162.
57. Trappey GJ, O'Connor DP, Edwards TB. What are the instability and infection rates after reverse shoulder arthroplasty? *Clin Orthop Related Res.* 2011;469(September (9)):2505–2511.
58. Teusink MJ, Pappou IP, Schwartz DG, Cottrell BJ, Frankle MA. Results of closed management of acute dislocation after reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2015;24(April (4)):621–627.
59. Boulahia A, Edwards TB, Walch G, Baratta RV. Early results of a reverse design prosthesis in the treatment of arthritis of the shoulder in elderly patients with a large rotator cuff tear. *Orthopedics.* 2002;25(2):129–133.
60. Favre P, Sussmann PS, Gerber C. The effect of component positioning on intrinsic stability of the reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2010;19(4):550–556.
61. Edwards TB, Williams MD, Labriola JE, Elkousy HA, Gartsman GM, O'Connor DP. Subscapularis insufficiency and the risk of shoulder dislocation after reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2009;18(6):892–896.
62. Beekman PD, Katusic D, Berghs BM, Karelse A, De Wilde L. One-stage revision for patients with a chronically infected reverse total shoulder replacement. *J Bone Joint Surg Br.* 2010;92(6):817–822.
63. Richards J, Inacio MC, Beckett M, et al. Patient and procedure-specific risk factors for deep infection after primary shoulder arthroplasty. *Clin Orthop Related Res.* 2014;472(September (9)):2809–2815.
64. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. *J Bone Joint Surg Am.* 2007;89(3):588–600.
65. Levigne C, Boileau P, Favard L, et al. Scapular notching in reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2008;17(6):925–935.
66. Valenti P, Sauzieres P, Katz D, Kalouche I, Kilinc AS. Do less medialized reverse shoulder prostheses increase motion and reduce notching? *Clin Orthop Relat Res.* 2011;469(9):2550–2557.
67. Ladermann A, Lubbeke A, Melis B, et al. Prevalence of neurologic lesions after total shoulder arthroplasty. *J Bone Joint Surg Am.* 2011;93(14):1288–1293.
68. Nagda SH, Rogers KJ, Sestokas AK, et al. Neer Award 2005: peripheral nerve function during shoulder arthroplasty using intraoperative nerve monitoring. *J Shoulder Elbow Surg.* 2007;16(June (3)):S2–8.
69. Ladermann A, Denard PJ, Boileau P, et al. Effect of humeral stem design on humeral position and range of motion in reverse shoulder arthroplasty. *Int Orthop.* 2015;39(November (11)):2205–2213.
70. Melis B, DeFranco M, Ladermann A, et al. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. *J Bone Joint Surg Br.* 2011;93(September (9)):1240–1246.
71. Alentorn-Geli E, Guirro P, Santana F, Torrens C. Treatment of fracture sequelae of the proximal humerus: comparison of hemiarthroplasty and reverse total shoulder arthroplasty. *Arch Orthop Trauma Surg.* 2014;134(November (11)):1545–1550.
72. Walch G, Mottier F, Wall B, Boileau P, Mole D, Favard L. Acromial insufficiency in reverse shoulder arthroplasties. *J Shoulder Elbow Surg.* 2009;18(3):495–502.
73. Wahlquist TC, Hunt AF, Braman JP. Acromial base fractures after reverse total shoulder arthroplasty: report of five cases. *J Shoulder Elbow Surg.* 2011;20(October (7)):1178–1183.
74. Boulahia A, Edwards TB, Walch G, Baratta RV. Early results of a reverse design prosthesis in the treatment of arthritis of the shoulder in elderly patients with a large rotator cuff tear. *Orthopedics.* 1992;25:129–133.
75. Grammont PM, Baulot E, Chabernaud D. Résultats des 16 premiers cas d'arthroplastie totale d'épaule inversée sans ciment pour des omarthroses avec grande rupture de coiffe. *Rev Chir Orthop Reparatrice Appar Mot.* 1996;82(Suppl 1):169.
76. DeButtet M, Bouchon Y, Capon D, Delfosse J. Grammont shoulder arthroplasty for osteoarthritis with massive rotator cuff tears: report of 71 cases. *J Shoulder Elbow Surg.* 1997;6:197.
77. Jacobs R, Debeer P, De Smet L. Treatment of rotator cuff arthropathy with a reversed Delta shoulder prosthesis. *Acta Orthop Belg.* 2001;67:344–347.
78. Valenti PH, Boutens D, Nerot C. GED. Delta 3 reversed prosthesis for osteoarthritis with massive rotator cuff tear: long term results (> 5 years). Walch G, Boileau P, Molé D, eds. *Shoulder Prosthesis: Two to Ten Year Follow-up*, 2001 Montpelier: Sauramps Médical; 2000.