Soft tissue balancing in total shoulder replacement

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Abstract Total shoulder arthroplasty is now capable of recreating near anatomic reproduction of native bony shoulder anatomy, but the function and longevity of anatomic shoulder replacement is dependent on a competent soft tissue envelope and adequate motoring of all musculo-tendinous units about the shoulder. Balancing the soft tissues requires understanding of the anatomy and pathology, as well as technical skills. The advent of reverse shoulder biomechanics has brought with it special requirements of understanding of the soft tissue elements still left in the shoulder despite major rotator cuff deficiency.

Keywords Shoulder arthroplasty · Rotator cuff deficiency · Shoulder replacement failure · Shoulder replacement instability

Introduction

Total shoulder arthroplasty (TSA) has become a commonplace [1] and accepted management [2] for the arthritic shoulder, in both young [3–6] and old [7]. However, functional outcomes are determined by many factors including variable expectations (with the young having higher than the old) [8], anatomic factors such as glenoid erosion [9] and accurate placement of the components of the prosthesis, but also by careful and appropriate management of the “soft tissue envelope” including rotator cuff elements, capsular elements, and neurovascular elements [10–12].

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Shoulder arthritis has a propensity for uneven wear of the glenoid in particular, and current prosthetic design developments [13] are attempting to balance the soft tissue envelope better by correcting (partially or completely) the glenoid bony deficiency [14]. There are recent suggestions that the B2 glenoid warrants primary reverse shoulder arthroplasty (RSA) due to late complications with anatomic arthroplasty [4].

Most reviews of primary shoulder replacement surgery discuss tendon release of the subscapularis (SSC), capsular release of the inferior capsule, and occasionally capsulorrhaphy of the posterior capsule for posterior laxity. Most do **not** address the fact that the bony positioning of a shoulder implant determines the length of the muscle-tendon units of the rotator cuff about the shoulder and that the sequelae of not respecting the soft tissue difficulties imperils the functional outcome of the replacement [15].

Prosthesis factors

Modular replacements

A recent explosion in commercial designs and availability of shoulder replacements [16] has led to the availability of modular components (Fig. 1), different biomaterials such as pyrocarbon [17, 18] and ceramics, and hybrid bony connections (part bony ingrowth/ongrowth, part cemented) [19]. Although hand surgeons recognize the different soft tissue response to various metals and polishes, shoulder biomaterials have not received such attention, and the effect of border lubrication on capsular responses is as yet not published.

Humeral version

The anatomic retroversion of the humeral head was ignored in early shoulder prosthesis designs, and more recently,

Fig. 1 Modern modular components of TSR

modularity and offset correction has made an anatomical replacement of the pre-existing shoulder alignment possible. This goal of insertion presupposes that the balance of the musculo-tendinous sleeve is corrected by returning to the original geometry of the shoulder joint [20]. Many outcomes studies have shown good results despite having no measure of the correction or otherwise of the bony anatomy, although the incidence of prosthetic instability has been tied to the degree of version of the humerus in some studies [21, 22]

Glenoid deficiency

Almost all osteoarthritic wear in the glenoid is posterior, and retroversion angles as high as 40° are encountered [22]. Both concentric and eccentric wear patterns create a grading of glenoid posterior wear that is in common use now, with the B2 glenoid producing the most discussion on optimum treatment when replacing the glenoid [21, 22].

Placing the glenoid component directly on the worn face of the remaining glenoid bone stock does not correct the glenoid orientation [23] and, thus, creates a relative mismatch in the subscapularis (SSC) to infraspinatus (ISP) length [15], which can either produce posterior prosthetic instability, or at the very least a muscle with suboptimum length-tension relationship with subsequent weakness. Green and Norris report that the SSC, if left contracted adds to this imbalance and further promotes the posterior instability [24].

The inability of shoulder replacements to achieve reliable results in patients with B2 and C glenoid types [25] has led to a call for B2 glenoid shapes in osteoarthritis being managed with a primary reverse geometry shoulder arthroplasty (RSA) [26]. This produces satisfactory function, but limits the goals of rotation in particular, and we have yet to see the long term sequelae of these prostheses in younger patients.

Correcting this soft-tissue imbalance is through correction of the bony deficit. This was historically done by reaming down the (usually anterior) high side to make the glenoid axis more normal, but was associated with medialization of the glenoid and/or deficient glenoid bone stock to support the glenoid prosthesis [27].

The recent development of patient specific guides for exact centering of the glenoid guide pin [28–30] has allowed for optimum alignment of the pin, but has not resulted in solutions for how to make the glenoid face anatomic to correct the muscular imbalance of subscapularis and infraspinatus.

Bone grafts have been used historically for normalizing the glenoid version, but have mixed published results [31].

More recently, commercial research has led to alternatives such as through built up prostheses made from uneven thicknesses of polyethylene [32, 33] or metal wedges. Further outcome studies are required to determine if they offer a better result than previous techniques.

Long head of biceps pathology

This discussion is short, as most authors recommend long head of biceps (LHB) tenodesis with total shoulder arthroplasty. Better external rotation of the humerus is achieved following LHB release intraoperatively, and evidence of loss of function after tenodesis is sparse. In reverse shoulder arthroplasty, it cannot be preserved as the tendon excursion does not coincide with the reverse geometry biomechanics.

Subscapularis pathology

The subscapularis tendon is the “doorway to the shoulder joint” and so is usually taken down for access to replace the shoulder. Recent novel techniques preserving SSC have been tried with inconsistent results to date [34].

Chronic SSC deficiency from past rupture is a relative contraindication for anatomic shoulder replacement, and unless a partial tear can be repaired solidly, may indicate the need for RSA [35].

Postoperative loss of SSC function [36] is discussed at length due to alternative surgical approaches of lesser tuberosity osteotomy and SSC takedown (either mid-substance or at insertion) [37, 38]. The alternatives assume normal SSC length, as the step cut alternatives all require an intact tendon to bone interface. When a patient ruptures the subscapularis post-total shoulder arthroplasty, the management becomes important for preventing prosthetic dislocation [39], and the use of Pectoralis Major as a transfer is now well recognized [40, 41].

Much more common in the pre-arthroplasty patient is a subscapularis and/or anterior capsular contracture [15], especially after an iatrogenic result of the “Putti Platt” instability

reconstruction in the 1960s and 1970s. This results in a short SSC tendon that cannot be “released” to normal length, and so often requires a lengthening procedure [42]. Various lengthening techniques are described, including vertical step cut, coronal step cut, and bony release with medialization of origin [42, 43].

Supraspinatus pathology

Although the native shoulder tolerates small, medium, and occasionally large supraspinatus (SSP) rotator cuff tears with relative ease, the same cannot be said of the prosthetic shoulder. Anatomic replacement does not stop superior migration of the humeral head when SSP deficiency is present, and even late supraspinatus rupture after total shoulder arthroplasty results in poorly functioning shoulders. Very small tears of supraspinatus are easily repaired at the time of surgery [44], but once proximal or superior migration has occurred, the cuff “incompetence” is likely to result in a failed cuff postoperatively, with recurrent superior migration, eccentric wear on the superior glenoid with possible earlier loosening or dissociation, and loss of shoulder elevation if the deltoid does not have compensatory strength [10, 40].

Prior to the widespread development of reverse shoulder arthroplasty options, the prosthetic “answer” to supraspinatus deficiency was the use of oversized humeral heads, or “CTA” head hemiarthroplasty [45], or bipolar humeral head replacements [46]. The aim of course was to increase the lever arm of the deltoid muscle and allow it to elevate the arm without the supraspinatus contribution. Some spectacular results followed, but many poor outcomes as well.

The RSA has generally overtaken the concept of TSA with concomitant SSP repair or reconstruction.

Infraspinatus and teres minor pathology

Poor infraspinatus (ISP) function has recently been shown to produce inferior results in TSA [10, 47]. Because of the association of infraspinatus dysfunction with supraspinatus deficiency, this has been addressed by having these patients selected for RSA rather than TSA as a primary operation. In the young patient, this is a significant reduction in outcome goals, and if salvage by repair or reconstruction is possible it should be considered [15].

Our understanding of ISP being the primary motor for external rotation has been challenged as more patients undergo RSA and Teres Minor deficiency has been associated with the “Hornblower’s Sign” of the abducted arm [41] being unable to hold enough external rotation to keep the hand elevated for simple functions like washing and brushing one’s hair.

As a result, the little used Latissimus Dorsi tendon transfer [48] has undergone somewhat of a renaissance being used in

particular with reverse shoulder replacements to avoid a continuing deficiency of external rotation in elevation postoperatively [49].

Techniques of insertion

Exposure

Total shoulder replacement is usually performed through a delto-pectoral incision. The deltoid and its axillary nerve supply is at some risk [12] but if a revision procedure is considered the clavicular portion of the deltoid origin can be taken off the clavicle with a sliver of bone [50] for later reattachment with transosseous sutures, and if the glenoid requires extra exposure, the coracoid can be taken down after predrilling to allow reattachment with screw fixation [51].

The subscapularis requires reflection from its insertion in most cases, although attempts at tendon-on shoulder replacement are published with variable results [34]. A minimally invasive double window approach has also been suggested [50]. There is much debate about lesser tuberosity osteotomy vs subscapularis tenotomy (insertion or mid-substance) [52], with some suggestions that the subscapularis function is less compromised by osteotomy [52]. Release of the capsular attachments to the subscapularis allows better lengthening of the tendon and good postoperative function [53, 54].

Humeral head exposure and replacement

Anatomic positioning [55] and version is the current procedure of choice [56, 57]. The correction of the edge of the humeral head with modular components has decreased the metal edge cutting into the adjacent cuff attachment [58]. The soft tissue effects of ceramic heads, pyrocarbon heads [17, 18], and metal partial resurfacing are not published as yet.

Glenoid exposure and replacement

Rapidly changing types of glenoid replacements are emerging. The effect of metallosis on the soft tissue [59] has brought about the advent of many “hybrid” glenoid components [19] as well as new age cementless techniques [60].

Hemiarthroplasty with “ream and run” glenoid techniques are widely published [27], but the scar response of the soft tissues from revision to total shoulder replacement can be significant, with outcomes showing less range of motion and strength, and high revision rates [61].

Posterior capsulorrhaphy

Many descriptions of shoulder replacement implantation describe checking posterior translation after trial insertion, and

performing posterior capsulorrhaphy to tighten any potential posterior laxity [62].

Postoperative outcomes

The expected outcomes of pain relief have been well documented [2], but range of motion and strength outcomes rely on the soft tissue effects of shoulder arthroplasty, and thus are less predictable.

Rehabilitation

The rehabilitation of shoulder arthroplasties has been colored by a lack of scientific rigor in assessing the effects of individual components on outcome [63]. Physician directed rehabilitation has been preferred by many [64], but a modern day collaborative approach is still considered the best time efficient method of rehabilitation of these patients.

Early protection of the subscapularis is essential to its' integrity [39, 52, 65], with 4–6 weeks of bracing, with active range of motion and strength exercises starting at 6 weeks both “dry” and in water, and a total 6-month rehabilitation plan [63].

Total shoulder arthroplasty soft tissue failures

Postoperative cuff deficiencies

Subscapularis deficiency has been well recognized after early failure of the surgical repair [66]. This is a failure of the approach to the joint. Postoperative anterior instability of total shoulder arthroplasty can be blamed primarily on this deficiency. Late rotator cuff deficiency includes all elements of the cuff [40], but management includes both tendon transfers [41] as discussed earlier or revision to a reverse shoulder arthroplasty [67].

Postoperative stiffness

The most likely cause of postoperative stiffness is preoperative stiffness and not performing adequate surgical releases at the time of surgery to recover adequate range of motion. However, common associated features are malposition of prosthesis and instability [68]. Whatever the cause, after failure to progress with nonoperative means, surgical release is often helpful [69].

Other recently published causes of stiffness include infection, and the involvement of *Propionibacterium Acnes* in the production of postsurgical stiffness has been suggested [70]. This micro-organism has been under reported for many years

due to the 7- to 10-day period for positive cultures [71], and in many Microbiology labs the specimens are discarded before this time.

Conclusions

Anatomic total shoulder arthroplasty offers the best chance of normalized function of the arthritic shoulder after surgery. However, the competence, strength, and mobility of the soft tissue elements surrounding the shoulder are what give it the best range of motion, strength, and coordination. Recent published literature has focused on cuff deficiency being treated by reverse geometry shoulder arthroplasty techniques, but this does not offer normalization of the shoulder biomechanics, and this review demonstrates the difficulties of solving soft tissue scarring and deficiencies around shoulder prostheses. New developments in biomaterials, built up prosthetic options, and soft tissue augmentation may further improve outcomes.

Compliance with Ethics Guidelines

Conflict of Interest Maïke Mueller declares no conflicts of interest. Gregory Hoy receives travel/accommodation expenses from, and is a paid consultant for Depuy Synthes and Integra; he also receives payment for development of educational presentations from Depuy Synthes.

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References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Rasmussen JV, Olsen BS, Fevang BT, Furnes O, Skytta ET, Rahme H, et al. A review of national shoulder and elbow joint replacement registries. *J Shoulder Elbow Surg.* 2012;21:1328–35. doi:10.1016/j.jse.2012.03.004. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
2. Carter MJ, Mikuls TR, Nayak S, Fehring EV, Michaud K. Impact of total shoulder arthroplasty on generic and shoulder-specific health-related quality-of-life measures: a systematic literature review and meta-analysis. *J Bone Joint Surg Am.* 2012;94:e127. doi: 10.2106/JBJS.K.00204.
3. Burroughs PL, Gearen PF, Petty WR, Wright TW. Shoulder arthroplasty in the young patient. *J Arthroplasty.* 2003;18:792–8.
4. Denard PJ, Raiss P, Sowa B, Walch G. Mid- to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. *J Shoulder Elbow Surg.* 2013;22:894–900. doi:10.1016/j.jse.2012.09.016. *National Joint*

- Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
5. Merolla G, Bianchi P, Lollino N, Rossi R, Paladini P, Porcellini G. Clinical and radiographic mid-term outcomes after shoulder resurfacing in patients aged 50 years old or younger. *Musculoskel Surg.* 2013;97 Suppl 1:23–9. doi:10.1007/s12306-013-0261-4.
 6. Raiss P, Aldinger PR, Kasten P, Rickert M, Loew M. Total shoulder replacement in young and middle-aged patients with glenohumeral osteoarthritis. *J Bone Joint Surg Br.* 2008;90:764–9. doi:10.1302/0301-620X.90B6.20387. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 7. Foruria AM, Sperling JW, Ankem HK, Oh LS, Cofield RH. Total shoulder replacement for osteoarthritis in patients 80 years of age and older. *J Bone Joint Surg Br.* 2010;92:970–4. doi:10.1302/0301-620X.92B7.23671.
 8. Henn III RF, Ghomrawi H, Rutledge JR, Mazumdar M, Mancuso CA, Marx RG. Preoperative patient expectations of total shoulder arthroplasty. *J Bone Joint Surg Am.* 2011;93:2110–5. doi:10.2106/JBJS.J.01114.
 9. Schrupf M, Maak T, Hammoud S, Craig EV. The glenoid in total shoulder arthroplasty. *Curr Rev Musculoskel Med.* 2011;4:191–9. doi:10.1007/s12178-011-9096-5.
 10. Young AA, Walch G, Pape G, Gohlke F, Favard L. Secondary rotator cuff dysfunction following total shoulder arthroplasty for primary glenohumeral osteoarthritis: results of a multicenter study with more than 5 years of follow-up. *J Bone Joint Surg Am.* 2012;94:685–93. doi:10.2106/JBJS.J.00727. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 11. Dines D. Late-onset rotator cuff dysfunction after total shoulder arthroplasty—the “forgotten” complication. Commentary on an article by Allan A. Young, MD, et al. “Secondary rotator cuff dysfunction following total shoulder arthroplasty for primary glenohumeral osteoarthritis: results of a multicenter study with more than 5 years of follow-up”. *J Bone Joint Surg Am.* 2012;94:e53. doi:10.2106/jbjs.k.00486.
 12. Ladermann A, Lubbeke A, Melis B, Stern R, Christofilopoulos P, Bacle G, et al. Prevalence of neurologic lesions after total shoulder arthroplasty. *J Bone Joint Surg Am.* 2011;93:1288–93. doi:10.2106/JBJS.J.00369.
 13. Churchill RS. Trends in glenoid component design in unconstrained shoulder arthroplasty. *JSES.* 2011;20:s41–s6. doi:10.1016/j.jse.2010.10.036.
 14. Bell RH, Noble JS. The management of significant glenoid deficiency in total shoulder arthroplasty. *J Shoulder Elbow Surg.* 2000;9:248–56.
 15. Abboud Ja Fau-Anakwenze OA. [J Am Acad Orthop Surg. 2012;21:23–31. doi:10.5435/JAAOS-21-01-23 2012 Abboud.pdf]. doi:10.5435/.
 16. <http://depts.washington.edu/shoulder/ListShoulderProstheses.htm>. Accessed 9 Sept 2013.
 17. Hardaker RN. Pyrocarbon joint resurfacing of the shoulder: is it clinically safe and effective? At http://www.acc.co.nz/PRD_EXT_CSMP/groups/external_communications/documents/reports_results/wpc118144.pdf. Accessed Sept. 9 2013.
 18. Mansat P, Coutié A-S, Bonneville N, Rongires M, Mansat M, Bonneville P. Resurfacing humeral prosthesis: do we really reconstruct the anatomy? *J Shoulder Elbow Surg.* 2013;22:612–619. doi:10.1016/j.jse.2012.07.014. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 19. Churchill RS. Trends in glenoid component design in unconstrained shoulder arthroplasty. *J Shoulder Elbow Surg.* 2011;20(2):S41–6. doi:10.1016/j.jse.2010.10.036.
 20. Gerber C, Costouros JG, Sukthankar A, Fucentese SF. Static posterior humeral head subluxation and total shoulder arthroplasty. *J Shoulder Elbow Surg.* 2009;18:505–10. doi:10.1016/j.jse.2009.03.003.
 21. Spencer Jr EE, Valdevit A, Kambic H, Brems JJ, Iannotti JP. The effect of humeral component anteversion on shoulder stability with glenoid component retroversion. *J Bone Joint Surg Am.* 2005;87:808–14. doi:10.2106/JBJS.C.00770.
 22. Sears BW, Johnston PS, Ramsey ML, Williams GR. Glenoid bone loss in primary total shoulder arthroplasty: evaluation and management. *J Am Acad Orthop Surg.* 2012;20:604–13. doi:10.5435/JAAOS-20-09-604.
 23. Gregory T, Hansen U, Emery R, Amis AA, Mutchler C, Taillieu F, et al. Total shoulder arthroplasty does not correct the orientation of the eroded glenoid. *Acta Orthop.* 2012;83:529–35.
 24. Green A, Norris TR. Shoulder arthroplasty for advanced glenohumeral arthritis after anterior instability repair. *J Shoulder Elbow Surg.* 2001;10:539–45. doi:10.1067/mse.2001.118007.
 25. Denard PJ, Walch G. Current concepts in the surgical management of primary glenohumeral arthritis with a biconcave glenoid. *J Shoulder Elbow Surg.* 2013;22:1589–98.
 26. Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. *J Bone Joint Surg Am.* 2013;95:1297–304. doi:10.2106/JBJS.L.00820. *The notion that reverse shoulder arthroplasty results are better than orthodox shoulder arthroplasties for B2 glenoids is both controversial and arguable on many grounds*
 27. Gilmer BB, Comstock BA, Jette JL, Warme WJ, Jackins SE, Matsen FA. The prognosis for improvement in comfort and function after the ream-and-run arthroplasty for glenohumeral arthritis: an analysis of 176 consecutive cases. *J Bone Joint Surg.* 2012;94:e102:1–9.
 28. Trouilloud P, Gonzalez M, Martz P, Charles H, Handelberg F, Nyffeler R, et al. Duocentric reversed shoulder prosthesis and personal fit templates: innovative strategies to optimize prosthesis positioning and prevent scapular notching. *Eur J Orthopaed Surg Traumatol.* 2013:1–13.
 29. Iannotti JP, Ricchetti ET, Rodriguez EJ, Bryan JA. Development and validation of a new method of 3-dimensional assessment of glenoid and humeral component position after total shoulder arthroplasty. *J Shoulder Elbow Surg.* 2013;22:1413–22. doi:10.1016/j.jse.2013.01.005.
 30. Ekelund A, editor. New Trends in Shoulder Arthroplasty. European Instructional Lectures: Volume 13, 2013, 14th EFORT Congress, Istanbul, Turkey; Springer; 2013.
 31. Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis with severe glenoid bone loss. *J Bone Joint Surg Am.* 2013;95:1290–6. doi:10.2106/JBJS.L.00097.
 32. Iannotti JP, Lappin KE, Klotz CL, Reber EW, Swope SW. Lift-off resistance of augmented glenoid components during cyclic fatigue loading in the posterior-superior direction. *J Shoulder Elbow Surg.* 2013. doi:10.1016/j.jse.2013.01.018. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 33. Hermida JC, Flores-Hernandez C, Hoenecke HR, D’Lima DD. Augmented wedge-shaped glenoid component for the correction of glenoid retroversion: a finite element analysis. *J Shoulder Elbow Surg.* 2013. doi:10.1016/j.jse.2013.06.008.
 34. Lafosse L, Schnaser E, Haag M, Gobeze R. Primary total shoulder arthroplasty performed entirely thru the rotator interval: technique and minimum two-year outcomes. *J Shoulder Elbow Surg.* 2009;18:864–73. doi:10.1016/j.jse.2009.03.017.
 35. Terrier A, Larrea X, Malfroy Camine V, Pioletti D, Farron A. Importance of the subscapularis muscle after total shoulder

- arthroplasty. Clin Biomech. 2013;28:146–50. doi:[10.1016/j.clinbiomech.2012.11.010](https://doi.org/10.1016/j.clinbiomech.2012.11.010).
36. Ives EP, Nazarian LN, Parker L, Garrigues GE, Williams GR. Subscapularis tendon tears: a common sonographic finding in symptomatic postarthroplasty shoulders. J Clin Ultrasound. 2013;41:129–33. doi:[10.1002/jcu.21980](https://doi.org/10.1002/jcu.21980)
 37. Sperling JW, editor. Subscapularis Tenotomy: Optimal Approach to Shoulder Replacement: Affirms. Seminars in Arthroplasty; Elsevier; 2012.
 38. Van den Berghe GR, Nguyen B, Patil S, D'Lima DD, Mahar A, Pedowitz R, et al. A biomechanical evaluation of three surgical techniques for subscapularis repair. J Shoulder Elbow Surg. 2008;17:156–61. doi:[10.1016/j.jse.2007.04.016](https://doi.org/10.1016/j.jse.2007.04.016).
 39. Miller BS, Joseph TA, Noonan TJ, Horan MP, Hawkins RJ. Rupture of the subscapularis tendon after shoulder arthroplasty: diagnosis, treatment, and outcome. J Shoulder Elbow Surg. 2005;14:492–6. doi:[10.1016/j.jse.2005.02.013](https://doi.org/10.1016/j.jse.2005.02.013).
 40. Blalock R, Galatz LM, editors. Rotator Cuff Tears After Arthroplasty. Seminars in Arthroplasty; Elsevier; 2012.
 41. Talbot JC, Watts AC, Grimberg J, Funk L. Shoulder tendon transfers for rotator cuff deficiency. Shoulder Elbow. 2013;5:1–11.
 42. Nicholson GP, Twigg S, Blatz B, Sturonas-Brown B and Wilson J. Subscapularis Lengthening in Shoulder Arthroplasty. J Shoulder Elbow Surg. 2010;19:427–33. doi:[10.1016/j.jse.2009.05.017](https://doi.org/10.1016/j.jse.2009.05.017).
 43. Van Thiel GS, Wang VM, Wang FC, Nho SJ, Piasecki DP, Bach Jr BR, et al. Biomechanical similarities among subscapularis repairs after shoulder arthroplasty. J Shoulder Elbow Surg. 2010;19:657–63. doi:[10.1016/j.jse.2010.01.014](https://doi.org/10.1016/j.jse.2010.01.014).
 44. Edwards TB. Shoulder replacement surgery. Orthopedics. 2012;35:865–6.
 45. Firestone D, Arnold RM, Fehringer EV. Two-year follow-up of shoulder hemiarthroplasty with a CTA head for cuff-tear arthropathy. Shoulder Elbow. 2012;4:174–8.
 46. Moen TC, Hsu SH, Bigliani LU, editors. Intraoperative Issues Dictated by Diagnosis: Cuff Deficiency: Allograft, Transfer, or Advance. Seminars in Arthroplasty; Elsevier; 2012;23:68–73.
 47. Lo EY, Moen TC, Burkhead WZ, editors. Instability failure in total shoulder arthroplasty. Seminars in Arthroplasty; Elsevier; 2013;24:28–32.
 48. Namdari S, Voleti P, Baldwin K, Glaser D, Huffman GR. Latissimus Dorsi tendon transfer for irreparable rotator cuff tears: a systematic review. J Bone Joint Surg. 2012;94:891–8.
 49. Puskas GJ, Catanzaro S, Gerber C. Clinical outcome of reverse total shoulder arthroplasty combined with latissimus dorsi transfer for the treatment of chronic combined pseudoparesis of elevation and external rotation of the shoulder. J Shoulder Elbow Surg. 2014;23:49–57. *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 50. Redfern T, Wallace W, Beddow F. Clavicular osteotomy in shoulder arthroplasty. Int Orthopaed. 1989;13:61–3.
 51. Hoppenfeld S, Buckley R. Surgical exposures in orthopaedics: the anatomic approach. Philadelphia, USA; Lippincott Williams & Wilkins; 2012.
 52. Lapner PL, Sabri E, Rakhra K, Bell K, Athwal GS. Comparison of lesser tuberosity osteotomy to subscapularis peel in shoulder arthroplasty: a randomized controlled trial. J Bone Joint Surg Am. 2012;94:2239–46. doi:[10.2106/JBJS.K.01365](https://doi.org/10.2106/JBJS.K.01365).
 53. Fama G, Nava P, Pini S, Cossetini MM, Pozzuoli A. Management of the subscapularis contracture during shoulder arthroplasty for primary glenohumeral arthritis. La Chirurgia Degli Organi Di Movimento. 2008;91:71–7. doi:[10.1007/s12306-007-0012-5](https://doi.org/10.1007/s12306-007-0012-5).
 54. De Wilde LF, De Coninck T, De Neve F, Berghs BM. Subscapularis release in shoulder replacement determines structural muscular changes. Clin Orthopaed Rel Res. 2012;470:2193–201. doi:[10.1007/s11999-012-2291-x](https://doi.org/10.1007/s11999-012-2291-x).
 55. Hernigou P, Duparc F, Hernigou A. Determining humeral retroversion with computed tomography. J Bone Joint Surg Am. 2002;84A:1753–62.
 56. Boileau P, Walch G. The surgical anatomy and osteotomy technique for the humeral head. Shoulder Arthroplasty. New York, USA; Springer; 1999. pp. 105–23.
 57. Boileau P, Bicknell R, Mazzoleni N, Walch G, Urien J. CT scan method accurately assesses humeral head retroversion. Clin Orthopaed Rel Res. 2008;466:661–9.
 58. Sassoon A, Schoch B, Rhee P, Schleck C, Harmsen W, Sperling J, et al. The role of eccentric and offset humeral head variations in total shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22:886–93.
 59. Maccioni CB, Sonnabend D. Metal-backed glenoid prostheses. Shoulder & Elbow. 2013;5:217–220.
 60. Budge MD, Nolan EM, Heisey MH, Baker K, Wiater JM. Results of total shoulder arthroplasty with a monoblock porous tantalum glenoid component: a prospective minimum 2-year follow-up study. J Shoulder Elbow Surg. 2013;22:535–41.
 61. Levine WN, Fischer CR, Nguyen D, Flatow EL, Ahmad CS, Bigliani LU. Long-term follow-up of shoulder hemiarthroplasty for glenohumeral osteoarthritis. J Bone Joint Surg Am. 2012;94:e164. doi:[10.2106/JBJS.K.00603](https://doi.org/10.2106/JBJS.K.00603).
 62. Namba RS, Thornhill TS. Posterior capsulorrhaphy in total shoulder arthroplasty. A case report. Clin Orthopaed Rel Res. 1995:135–9.
 63. Fusaro I, Orsini S, Stignani S, Creta D, Cava F, Benedetti M. Proposal for SICSeG guidelines for rehabilitation after anatomical shoulder prosthesis in concentric shoulder osteoarthritis. Musculoskel Surg. 2013;97:31–7. doi:[10.1007/s12306-013-0257-0](https://doi.org/10.1007/s12306-013-0257-0)
 64. Groh GI, Groh GM. Complications rates, reoperation rates, and the learning curve in reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2013. doi:[10.1016/j.jse.2013.06.002](https://doi.org/10.1016/j.jse.2013.06.002)
 65. Jackson JD, Cil A, Smith J, Steinmann SP. Integrity and function of the subscapularis after total shoulder arthroplasty. J Shoulder Elbow Surg. American Shoulder and Elbow Surgeons, et al. 2010;19:1085–90. doi:[10.1016/j.jse.2010.04.001](https://doi.org/10.1016/j.jse.2010.04.001).
 66. Miller SL, Hazrati Y, Klepps S, Chiang A, Flatow EL. Loss of subscapularis function after total shoulder replacement: a seldom recognized problem. J Shoulder Elbow Surg. 2003;12:29–34.
 67. Abdel M, Hattrup S, Sperling J, Cofield R, Kreofsky C, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J. 2013;95:668–72.
 68. Hasan SS, Leith JM, Campbell B, Kapil R, Smith KL, Matsen III FA. Characteristics of unsatisfactory shoulder arthroplasties. J Shoulder Elbow Surg. 2002;11:431–41.
 69. Katthagen JC, Jensen G, Voigt C, Lill H. [Shoulder stiffness]. Der Unfallchirurg. 2012;115:527–38; quiz 39–40. doi:[10.1007/s00113-012-2234-8](https://doi.org/10.1007/s00113-012-2234-8). *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 70. Pottinger P, Butler-Wu S, Neradilek MB, Merritt A, Bertelsen A, Jette JL, et al. Prognostic factors for bacterial cultures positive for Propionibacterium acnes and other organisms in a large series of revision shoulder arthroplasties performed for stiffness, pain, or loosening. J Bone Joint Surg Am. 2012;94:2075–83. doi:[10.2106/JBJS.K.00861](https://doi.org/10.2106/JBJS.K.00861). *National Joint Registries will provide significant data for future claims both positive and negative regarding shoulder arthroplasty survivorship.*
 71. Shannon SK, Mandrekar J, Gustafson DR, Rucinski SL, Dailey AL, Segner RE, et al. Anaerobic thioglycolate broth culture for recovery of Propionibacterium acnes from shoulder tissue and fluid specimens. J Clin Microbiol. 2013;51:731–2.