Journal of
Clinical Medicine

MDPI

Editorial

The Evolution of Reverse Total Shoulder Arthroplasty—Where Do We Stand and What Comes Next?

Stefan Bauer [1,2] and Lukas Ernstbrunner [3,4,*]

[1] Service d'Orthopédie et de Traumatologie, Chirurgie de l'Épaule, Ensemble Hospitalier de la Côte, 1110 Morges, Switzerland
[2] Medical School, University of Western Australia, 35 Sterling Highway, Perth, WA 6009, Australia
[3] Department of Orthopaedic Surgery, Royal Melbourne Hospital, 300 Grattan Street, Parkville, Melbourne, VIC 3050, Australia
[4] Department of Biomedical Engineering, University of Melbourne, Parkville, VIC 3010, Australia
* Correspondence: lukas.ernstbrunner@icloud.com

Keywords: reverse total shoulder arthroplasty; history; biomechanics; lateralization; implant design; mixed reality

Over 35 years ago, the pioneer Paul Grammont from Lyon published his ideas of a reversed semi-constraint prosthesis improving the moment arm of the deltoid by medializing the center of rotation and lengthening of the arm and thus increasing deltoid muscle tension [1]. The original Grammont reverse total shoulder arthroplasty (RTSA) has undergone remarkable design improvements, thus not only relieving pain, but also reliably restoring shoulder "balance" and function especially for activities that require an upper limb that needs to be held and stabilized in space against gravity and weight [2,3]. These improvements include variable design configurations and glenoid-sided, humeral-sided and global lateralization with advantages such as reduced notching, increased range of motion and rotation, increased stability due to deltoid "wrapping" and higher joint reaction forces in elevated arm positions [4–8].

Due to the success of RTSA, indications have been expanded from irreparable cuff tears with and without osteoarthritis [9–13] to eccentric glenohumeral OA [14], rheumatoid arthritis [15], and proximal humeral fractures and their sequelae [16–18]. There are also advocates for RTSA over anatomic total shoulder arthroplasty (TSA) in concentric OA in elderly patients, and this appears justifiable since clinical results, patient satisfaction, and complications after RTSA and TSA in such patients do not show a significant difference with the exception of internal and external rotation in favor of TSA [19,20]. The increased utilization of RTSA is also displayed in the statistics of the largest worldwide shoulder arthroplasty registry, the Australian Joint Replacement Registry, including over 60,000 shoulder replacements implanted in 2021, of which around 80% were RTSA [21].

Remarkable developments around RTSA are available on the market including new preoperative planning software [22], augmented and mixed reality integration [23–25], and improved implant designs [4,5,26]. Together with increased surgical experience and knowledge about long-term results [11,27], it is thought that our results have become more reliable. However, at the same time, an increased number of RTSA-specific complications and failures are inevitable and complications are more frequently seen [28]. They include scapular notching [6,29,30], acromial and scapular spine stress fractures [31–36], humeral-sided and glenoid bone loss [37,38], instability [16,39], deltoid paralysis [40], and failure to restore sufficient internal [41,42] and external rotation [16,42]. Some of these complications can make revision surgery extremely challenging, requiring revision-specific preoperative planning tools [25], complex glenoid bone grafting procedures [43], or even custom-made implants [38].

check for updates

Citation: Bauer, S.; Ernstbrunner, L. The Evolution of Reverse Total Shoulder Arthroplasty—Where Do We Stand and What Comes Next? *J. Clin. Med.* **2023**, *12*, 1945. https://doi.org/10.3390/jcm12051945

Received: 21 February 2023
Accepted: 27 February 2023
Published: 1 March 2023

Besides this burden, we are at the brink of integrating artificial intelligence data into our planning process and using mixed reality tools and robotics for more precise execution of our surgical plans, and we have been starting to integrate the soft tissues [44] as well as scapulothoracic biomechanics [8] into our surgical decision making. Artificial intelligence, patient-specific implantation and implants, mixed reality, robotics, muscle-tendon and tissue planning, and integration of scapulothoracic motion will be some of the key elements of the journey of RTSA in the future.

The aim of this Special Issue is a comprehensive review of the literature on indications, the evolution of RTSA implant designs, biomechanical considerations, current trends and design specific outcomes, discussion and provision of evidence of potential benefits of preoperative planning tools, and to shed light on unsolved problems for ongoing study and optimization of RTSA in the future.

Author Contributions: Conceptualization: S.B. and L.E. Writing—original draft preparation: S.B. and L.E. Writing—review and editing: S.B. and L.E. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: Many thanks to the Australian Government for the support of this work as part of a Research Training Program PhD scholarship kindly granted for the first author (SB).

Conflicts of Interest: The authors declare no conflict of interest related to this work.

References

1. Grammont, P.; Trouilloud, P.; Laffay, J.; Deries, X. Etude et Réalisation d'une Nouvelle Prothèse d'épaule. Rhumatologie. 1987. Available online: https://www.semanticscholar.org/paper/Etude-et-r%C3%A9alisation-d%27une-nouvelle-proth%C3%A8se-Grammont-Trouilloud/ce86490e649299d28303798d257d14c9b2642fbe (accessed on 19 February 2023).
2. Bauer, S.; Okamoto, T.; Babic, S.M.; Coward, J.C.; Coron, C.M.P.L.; Blakeney, W.G. Understanding shoulder pseudoparalysis: Part I: Definition to diagnosis. *EFORT Open Rev.* **2022**, *7*, 214–226. [CrossRef] [PubMed]
3. Coward, J.C.; Bauer, S.; Babic, S.M.; Coron, C.; Okamoto, T.; Blakeney, W.G. Understanding shoulder pseudoparalysis. Part II: Treatment. *EFORT Open Rev.* **2022**, *7*, 227–239. [CrossRef] [PubMed]
4. Werthel, J.-D.; Walch, G.; Vegehan, E.; Deransart, P.; Sanchez-Sotelo, J.; Valenti, P. Lateralization in reverse shoulder arthroplasty: A descriptive analysis of different implants in current practice. *Int. Orthop.* **2019**, *43*, 2349–2360. [CrossRef]
5. Bauer, S.; Corbaz, J.; Athwal, G.S.; Walch, G.; Blakeney, W.G. Lateralization in Reverse Shoulder Arthroplasty. *J. Clin. Med.* **2021**, *10*, 5380. [CrossRef] [PubMed]
6. Bauer, S.; Blakeney, W.G.; Goyal, N.; Flayac, H.; Wang, A.; Corbaz, J. Posteroinferior relevant scapular neck offset in reverse shoulder arthroplasty: Key player for motion and friction-type impingement in a computer model. *J. Shoulder Elb. Surg.* **2022**, *31*, 2638–2646. [CrossRef] [PubMed]
7. Hamilton, M.A.; Diep, P.; Roche, C.; Flurin, P.H.; Wright, T.W.; Zuckerman, J.D.; Routman, H. Effect of reverse shoulder design philosophy on muscle moment arms. *J. Orthop. Res.* **2015**, *33*, 605–613. [CrossRef]
8. Bauer, S.; Blakeney, W.G.; Wang, A.W.; Ernstbrunner, L.; Corbaz, J.; Werthel, J.-D. Challenges for Optimization of Reverse Shoulder Arthroplasty Part II: Subacromial Space, Scapular Posture, Moment Arms and Muscle Tensioning. *J. Clin. Med.* **2023**, *12*, 1616. [CrossRef] [PubMed]
9. Mulieri, P.; Dunning, P.; Klein, S.; Pupello, D.; Frankle, M. Reverse Shoulder Arthroplasty for the Treatment of Irreparable Rotator Cuff Tear without Glenohumeral Arthritis. *J. Bone Jt. Surg.* **2010**, *92*, 2544–2556. [CrossRef]
10. Sirveaux, F.; Favard, L.; Oudet, D.; Huquet, D.; Walch, G.; Mole, D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. *J. Bone Jt. Surg.* **2004**, *86*, 388–395. [CrossRef]
11. Ernstbrunner, L.; Andronic, O.; Grubhofer, F.; Camenzind, R.S.; Wieser, K.; Gerber, C. Long-term results of reverse total shoulder arthroplasty for rotator cuff dysfunction: A systematic review of longitudinal outcomes. *J. Shoulder Elb. Surg.* **2019**, *28*, 774–781. [CrossRef] [PubMed]
12. Ernstbrunner, L.; Suter, A.; Catanzaro, S.; Rahm, S.; Gerber, C. Reverse Total Shoulder Arthroplasty for Massive, Irreparable Rotator Cuff Tears Before the Age of 60 Years: Long-Term Results. *J. Bone Jt. Surg. Am.* **2017**, *99*, 1721–1729. [CrossRef] [PubMed]
13. Gerber, C.; Canonica, S.; Catanzaro, S.; Ernstbrunner, L. Longitudinal observational study of reverse total shoulder arthroplasty for irreparable rotator cuff dysfunction: Results after 15 years. *J. Shoulder Elb. Surg.* **2018**, *27*, 831–838. [CrossRef] [PubMed]
14. Mehta, S.K.; Aleem, A.W. Management of the B2 Glenoid in Glenohumeral Osteoarthritis. *Orthop. Clin. N. Am.* **2019**, *50*, 509–520. [CrossRef] [PubMed]
15. Lévigne, C.; Chelli, M.; Johnston, T.R.; Trojani, M.-C.; Molé, D.; Walch, G.; Boileau, P. Reverse shoulder arthroplasty in rheumatoid arthritis: Survival and outcomes. *J. Shoulder Elb. Surg.* **2021**, *30*, 2312–2324. [CrossRef]

16. Kozak, T.; Bauer, S.; Walch, G.; Al-Karawi, S.; Blakeney, W. An update on reverse total shoulder arthroplasty: Current indications, new designs, same old problems. *EFORT Open Rev.* **2021**, *6*, 189–201. [CrossRef] [PubMed]
17. Ernstbrunner, L.; Rahm, S.; Suter, A.; Imam, M.A.; Catanzaro, S.; Grubhofer, F.; Gerber, C. Salvage reverse total shoulder arthroplasty for failed operative treatment of proximal humeral fractures in patients younger than 60 years: Long-term results. *J. Shoulder Elb. Surg.* **2020**, *29*, 561–570. [CrossRef] [PubMed]
18. Jo, O.; Borbas, P.; Grubhofer, F.; Ek, E.T.; Pullen, C.; Treseder, T.; Ernstbrunner, L. Prosthesis Designs and Tuberosity Fixation Techniques in Reverse Total Shoulder Arthroplasty: Influence on Tuberosity Healing in Proximal Humerus Fractures. *J. Clin. Med.* **2021**, *10*, 4146. [CrossRef]
19. Kirsch, J.M.; Puzzitiello, R.N.; Swanson, D.; Le, K.; Hart, P.A.; Churchill, R.; Elhassan, B.; Warner, J.J.; Jawa, A. Outcomes After Anatomic and Reverse Shoulder Arthroplasty for the Treatment of Glenohumeral Osteoarthritis: A Propensity Score-Matched Analysis. *J. Bone Jt. Surg. Am.* **2022**, *104*, 1362–1369. [CrossRef]
20. Hao, K.A.; Greene, A.T.; Werthel, J.-D.; Wright, J.O.; King, J.J.; Wright, T.W.; Vasilopoulos, T.; Schoch, B.S. Clinical Outcomes of Anatomic Versus Reverse Total Shoulder Arthroplasty in Primary Osteoarthritis with Preoperative Rotational Stiffness and an Intact Rotator Cuff: A Case Control Study. *J. Shoulder Elb. Surg.* **2023**. [CrossRef] [PubMed]
21. AOANJRR. Available online: https://aoanjrr.sahmri.com/annual-reports-2022 (accessed on 19 February 2023).
22. Walch, G.; Vezeridis, P.S.; Boileau, P.; Deransart, P.; Chaoui, J. Three-dimensional planning and use of patient-specific guides improve glenoid component position: An in vitro study. *J. Shoulder Elb. Surg.* **2015**, *24*, 302–309. [CrossRef] [PubMed]
23. Kriechling, P.; Loucas, R.; Loucas, M.; Casari, F.; Fürnstahl, P.; Wieser, K. Augmented reality through head-mounted display for navigation of baseplate component placement in reverse total shoulder arthroplasty: A cadaveric study. *Arch. Orthop. Trauma Surg.* **2023**, *143*, 169–175. [CrossRef] [PubMed]
24. Kriechling, P.; Roner, S.; Liebmann, F.; Casari, F.; Fürnstahl, P.; Wieser, K. Augmented reality for base plate component placement in reverse total shoulder arthroplasty: A feasibility study. *Arch. Orthop. Trauma Surg.* **2021**, *141*, 1447–1453. [CrossRef] [PubMed]
25. Italia, K.; Launay, M.; Gilliland, L.; Nielsen, J.; Pareyon, R.; Hollman, F.; Salhi, A.; Maharaj, J.; Jomaa, M.; Cutbush, K.; et al. Single-Stage Revision Reverse Shoulder Arthroplasty: Preoperative Planning, Surgical Technique, and Mixed Reality Execution. *J. Clin. Med.* **2022**, *11*, 7422. [CrossRef] [PubMed]
26. Jassim, S.S.; Ernstbrunner, L.; Ek, E.T. Does Humeral Component Version Affect Range of Motion and Clinical Outcomes in Reverse Total Shoulder Arthroplasty? A Systematic Review. *J. Clin. Med.* **2021**, *10*, 5745. [CrossRef]
27. Chelli, M.; Boileau, P.; Domos, P.; Clavert, P.; Berhouet, J.; Collin, P.; Walch, G.; Favard, L. Survivorship of Reverse Shoulder Arthroplasty According to Indication, Age and Gender. *J. Clin. Med.* **2022**, *11*, 2677. [CrossRef]
28. Huang, Y.; Ernstbrunner, L.; Robinson, D.L.; Lee, P.V.S.; Ackland, D.C. Complications of Reverse Total Shoulder Arthroplasty: A Computational Modelling Perspective. *J. Clin. Med.* **2021**, *10*, 5336. [CrossRef]
29. Melis, B.; DeFranco, M.; Lädermann, A.; Molé, D.; Favard, L.; Nérot, C.; Maynou, C.; Walch, G. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. *J. Bone Jt. Surg.* **2011**, *93*, 1240–1246. [CrossRef]
30. Simovitch, R.W.; Zumstein, M.A.; Lohri, E.; Helmy, N.; Gerber, C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. *J. Bone Jt. Surg. Am.* **2007**, *89*, 588–600. [CrossRef]
31. Levy, J.C.; Anderson, C.; Samson, A. Classification of Postoperative Acromial Fractures Following Reverse Shoulder Arthroplasty. *J. Bone Jt. Surg.* **2013**, *95*, e104. [CrossRef]
32. Neyton, L.; Erickson, J.; Ascione, F.; Bugelli, G.; Lunini, E.; Walch, G. Grammont Award 2018: Scapular fractures in reverse shoulder arthroplasty (Grammont style): Prevalence, functional, and radiographic results with minimum 5-year follow-up. *J. Shoulder Elb. Surg.* **2019**, *28*, 260–267. [CrossRef]
33. Bauer, S.; Traverso, A.; Walch, G. Locked 90°-double plating of scapular spine fracture after reverse shoulder arthroplasty with union and good outcome despite plate adjacent acromion fracture. *BMJ Case Rep.* **2020**, *13*, e234727. [CrossRef]
34. Cassidy, J.T.; Paszicsnyek, A.; Ernstbrunner, L.; Ek, E.T. Acromial and Scapular Spine Fractures following Reverse Total Shoulder Arthroplasty—A Systematic Review of Fixation Constructs and Techniques. *J. Clin. Med.* **2022**, *11*, 7025. [CrossRef] [PubMed]
35. Paszicsnyek, A.; Jo, O.; Rupasinghe, H.S.; Ackland, D.C.; Treseder, T.; Pullen, C.; Hoy, G.; Ek, E.T.; Ernstbrunner, L. Factors Influencing Acromial and Scapular Spine Strain after Reverse Total Shoulder Arthroplasty: A Systematic Review of Biomechanical Studies. *J. Clin. Med.* **2022**, *11*, 361. [CrossRef] [PubMed]
36. Schenk, P.; Aichmair, A.; Beeler, S.; Ernstbrunner, L.; Meyer, D.C.; Gerber, C. Acromial Fractures Following Reverse Total Shoulder Arthroplasty: A Cohort Controlled Analysis. *Orthopedics* **2020**, *43*, 15–22. [CrossRef]
37. Ernstbrunner, L.; Werthel, J.-D.; Wagner, E.; Hatta, T.; Sperling, J.W.; Cofield, R.H. Glenoid bone grafting in primary reverse total shoulder arthroplasty. *J. Shoulder Elb. Surg.* **2017**, *26*, 1441–1447. [CrossRef] [PubMed]
38. Ortmaier, R.; Wierer, G.; Gruber, M.S. Functional and Radiological Outcomes after Treatment with Custom-Made Glenoid Components in Revision Reverse Shoulder Arthroplasty. *J. Clin. Med.* **2022**, *11*, 551. [CrossRef]
39. Loucas, M.; Borbas, P.; Vetter, M.M.; Loucas, R.; Ernstbrunner, L.; Wieser, K. Risk Factors for Dislocation After Reverse Total Shoulder Arthroplasty: A Systematic Review and Meta-Analysis. *Orthopedics* **2022**, *45*, e303–e308. [CrossRef]
40. Elhassan, B.T.; Wagner, E.R.; Werthel, J.-D.; Lehanneur, M.; Lee, J. Outcome of reverse shoulder arthroplasty with pedicled pectoralis transfer in patients with deltoid paralysis. *J. Shoulder Elb. Surg.* **2018**, *27*, 96–103. [CrossRef]

41. Rol, M.; Favard, L.; Berhouet, J.; la Société d'orthopédie de l'Ouest (SOO). Factors associated with internal rotation outcomes after reverse shoulder arthroplasty. *Orthop. Traumatol. Surg. Res. OTSR* **2019**, *105*, 1515–1519. [CrossRef]
42. Bauer, S.; Blakeney, W.G.; Wang, A.W.; Ernstbrunner, L.; Werthel, J.-D.; Corbaz, J. Challenges for Optimization of Reverse Shoulder Arthroplasty Part I: External Rotation, Extension and Internal Rotation. *J. Clin. Med.* **2023**, *12*, 1814. [CrossRef]
43. Wagner, E.; Houdek, M.T.; Griffith, T.; Elhassan, B.T.; Sanchez-Sotelo, J.; Sperling, J.W.; Cofield, R.H. Glenoid Bone-Grafting in Revision to a Reverse Total Shoulder Arthroplasty. *J. Bone Jt. Surg. Am.* **2015**, *97*, 1653–1660. [CrossRef] [PubMed]
44. Werthel, J.-D.; de Casson, F.B.; Burdin, V.; Athwal, G.S.; Favard, L.; Chaoui, J.; Walch, G. CT-based volumetric assessment of rotator cuff muscle in shoulder arthroplasty preoperative planning. *Bone Jt. Open* **2021**, *2*, 552–561. [CrossRef] [PubMed]