Stemless Total Shoulder: A Review of Biomechanical Fixation and Recent Results

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Abstract
Introduction: Anatomic total shoulder arthroplasty is the replacement of the humeral head and glenoid surfaces with the goal of replicating normal anatomy. It is commonly utilized for patients with osteoarthritis, rheumatoid arthritis, and osteonecrosis, who have decreased range of motion (ROM), persistent pain, and loss of strength. Total shoulder Arthroplasty (TSA) is the third most common joint replacement in the United States. The incidence of TSA has been increasing, some data suggest that by the year 2025, TSA incidence may rise to 439,206 operations per year. In recent years, stemless total shoulder implants have become available.

Results: These implants preserve bone stock while decreasing complications such as osteolysis, stress shielding and periprosthetic fracture. Stemless implants improve anatomic reconstruction and biomechanical function of the shoulder joint.

Conclusion: Increasing amounts of data suggest stemless TSA to be a safe and effective technology that will become more common in the coming year.

Keywords
Arthroplasty, prosthesis, replacement, shoulder

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Introduction
Anatomic total shoulder arthroplasty is the replacement of the humeral head and glenoid surfaces with the goal of replicating normal anatomy as closely as possible.¹,² This operation is commonly utilized for patients with osteoarthritis, rheumatoid arthritis, and osteonecrosis, who have decreased range of motion (ROM), persistent pain, and loss of strength.³,⁴ Total shoulder Arthroplasty (TSA) is the third most common joint replacement in the United States.⁵,⁶ In 20,10,53,000 shoulder replacements were performed.⁷ The incidence of TSA has been increasing, some data suggest that by the year 2025, TSA incidence may rise to 4,39,206 operations per year.⁵,⁸

In 1974, Dr. Charles Neer was the first to report results of shoulder arthroplasty using a stemmed humeral prosthesis.⁹ Dr. Neer reported results from 46 shoulders and found 20 to have excellent outcomes, 20 to have satisfactory outcomes, and 6 to have unsatisfactory outcomes.¹⁰ The first design used by Dr. Neer was a monoblock, which had fixed geometry and a limited range of sizes making replicating the native anatomy challenging.³ Modular implants were introduced in the 1990’s to allow for better recreation of the native anatomy.³ Composed of a humeral stem and head component, these implants aimed to overcome the limitations of the monoblock design by accounting for the diameter of the medullary canal and different humeral variations, in addition to addressing soft tissue balancing.³,⁴ Modular designs incorporated different humeral head components accounting for differing depths, but lacked variability in terms of diameter.³ They also had relatively fixed geometry.³ These drawbacks of the modular design led to head oversizing, malpositioning, alterations in

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center of rotation and over tensioning of soft tissues. This resulted in impaired strength, increased wear on the glenoid component and stretching or tearing of the supraspinatus and subscapularis tendons. Modular designs were followed by adaptable implants designed to correct the positioning of the humeral head and account for different humeral shaft angles, retroversion angles, inclination angles, and medial and posterior offsets. These models allowed for adequate anatomy recreation and improved outcomes compared to their predecessors.

While adaptable implants were improved compared to early models, the humeral stem continued to cause complications. Load transfer through the implant and stem can precipitate bone resorption and osteolysis. This bone remodeling can lead to aseptic loosening, premature implant failure and increase the risk of periprosthetic humerus fracture. Periprosthetic humerus fractures range from 1.6 to 19.4%. During primary TSA endosteal notching from reaming, excessive external rotation or cortical breaching can cause fracture. Furthermore, revision operations have shown to be technically challenging where fracture rates range from 1.5% to 16% mainly caused by stem removal. In an effort to decrease stem-related complications, there has been progression to use shorter stemmed implants. This has culminated in completely stemless humeral components, which offer potential advantages of less stress shielding, fewer fractures, and fewer major complications. In 2016, Churchill and Athwal reported on the early designs and results of this new technology. At that time, only 1 implant, Simpliciti (Tornier, Bloomington, MN, USA), was available in the United States. Over the last 4 years, that number has rapidly expanded to include 3 additional models: Sidus (Biomet, Warsaw, IN, USA), Catalyst (Orthoscience, Naples, FL, USA), and Arthrosurface (Arthrex, Naples, FL, USA). Along with increased model availability, increasing publications of outcome data and numerous clinical trials have been conducted on stemless shoulder arthroplasty. The increased quantity of data warrants a review of the current literature to evaluate stemless total shoulder arthroplasty and its viability as a treatment option for patients requiring TSA.

**Current Implants**

**Fixation**

Implant fixation is obtained through direct contact with the cut surface of metaphyseal bone. This fixation must be adequate to provide the patient with a functioning, long-lasting, stable implant that maintains adequate strength and mobility. Osseointegration is the method by which long-term stability in all of these implants is sustained, except for Catalyst, which has a cemented option. Osseointegration has been defined as a direct contact between living bone and an implant.
without intervening fibrous tissue. To improve this process, manufacturers increase the porosity of implants to allow bone to grow into or on to the implant. Implants are either manufactured with this increased porosity or material can be added to assist this process. Grit blasting is a common method used to add osteoconductive materials such as calcium phosphate or hydroxyapatite.

Using finite element (FE) modeling of the Sidus implant to measure micromotion, Favre et al. found that 99% of the bone implant interface was less than 150um. That amount of micromotion allows for osseointegration, implying that this implant will allow for osseointegration and long term stability.

Furthermore, Berth et al. used single-photon emission computed tomography integrated with multidetector computed tomography (SPECT/CT) data to suggest that osseointegration was almost complete by 3 months in patients who received the Affinis Short Shoulder Prosthesis. During revision procedures, Beck et al. were able to confirm that primary stability of stemless implants had occurred. Together these studies suggest primary stability and osseointegration can be achieved with stemless implants.

Bone quality is an important factor to evaluate when considering stemless implants due to its direct interface with metaphyseal bone and its requirement for integration. It has been recommended that only patients with good bone quality receive stemless implants. This is due to the increased stress placed on and increased resorption of the available cancellous bone beneath the implant. In patients with poor bone quality this can increase the risk of humerus fracture and cause implant failure.

Berth et al. using SPECT/CT found higher bone uptake in the superior most region of the prosthesis. This finding is supported by Reeves et al. who found greatest resorption potential 0–15mm below the prosthesis with the most uptake between 0–5mm. A second peak of resorption potential was found near the termination of the fixation at 15–25mm beneath the resection line. The stress on the bone was similar to that of intact bone 30–40mm below the implant.

Using FE modeling, Reeves et al. predicted how different implant designs would change bone stress and strain responses. They found bone stress in cortical and trabecular bone to be greatest in the lateral region of interest (ROI). Lateral was defined as the region directly lateral to the center of the metaphyseal resection. It includes areas such as the greater tuberosity on the lateral cortex of the humerus. Multiple studies have found similar results. Lateral ROI stress and strain is important because this area is where postoperative radiolucency is most commonly found.

A study by Comenda et al. simulated different head implants and resected surfaces to determine bone loss. All proximal and interior ROIs had increased bone loss. These researchers suggested that models similar to the Shoulder Modular Replacement by Lima (San Daliele del Friuli, Italy), with a small central peg and 3 fins, may resect the most bone stock, but are also most likely to result in the least amount of bone loss. Eclipse type models, with a threaded cortical cage, preserved the most bone stock but ended up causing the most bone mass loss. Schmidutz et al. reported similar results, finding the presence of stress shielding between the rim and central stem of implants. Bone apposition and compressive strain in these implants led to an increase in uptake density in that location. The implants examined in this study were the Epoca RH (DePuy Synthes, USA) and Copeland (Biotem, USA), however, they examined the implants to evaluate resurfacing without the stemmed component, making this relevant to stemless TSA. Furthermore, they suggested load transfer may be improved when done through a rim around the implant, but it increases stress on bone. Other studies have found that centrally pegged implants and implants with a thin peripheral rim cause less bone resorption and less humeral head loosening than boundary crossing implants. Long-term clinical outcomes and survivability data are required to determine if central pegs and peripheral rims effect bone absorption.

Anatomic Reconstruction

Kadum and Von Engelhardt found that stemless implants adequately recreated the native shoulder anatomy. Pinto et al. found that when comparing stemmed and stemless TSA, patients who received a stemless implant had a more anatomic reconstruction of their humeral neck angle. The other dimensions studied (humeral head diameter, head height, head medial offset, lateral humeral offset, head centering, and anatomy reconstruction index) did not show significant differences between the techniques. These results hint to stemless TSA’s ability to better recreate the anatomy of the shoulder joint than stemmed implants due to their adaptability.

Anatomy recreation is important for proper functioning of a TSA. Height of the prosthesis should be considered when recreating a patient’s anatomy during shoulder arthroplasty. Nyffeler et al. found insertion of prostheses at 5 and 10mm height offset reduced the maximum abduction angle by an average of 10° and 16° respectively. Height offset reduced the moment arms of the infraspinatus and subscapularis by 4 to 10mm, which corresponded with a 20–50% reduction in moment arms of the infraspinatus and a 50–100% decrease of...
abduction moment arms of the subscapularis. Proper anatomic recreation of the shoulder is required to prevent weakness, prevent impaired mobility, and ensure proper biomechanical functioning of the joint.

**Clinical Outcomes Data**

Stemless shoulder arthroplasty may offer a number of potential clinical advantages while reducing stem-related complications. It has been suggested that when compared with stemmed implants, stemless implants better recreate the native anatomy of the shoulder, decrease operation time with less blood loss, reduce stress shielding, improve bone stock preservation allowing for ease of revision, reduce risk of loosening of the stemmed component, and improve stability and load transfer via metaphyseal anchoring. Complications such as periprosthetic and intraoperative humeral fractures are associated with stemmed implants that are believed to be reduced with the use of stemless implants. Periprosthetic humeral fractures have been reported to be between 1.6 and 2.4%, and intraoperative humeral fractures at 1.5% for stemmed implants. Stem-related complications such as periprosthetic fractures have been reported to be between 1.2% and 19.4%.

A study in 2010 using the TESS (Biomet, Warsaw, IN, USA) implant with a minimum of 36-month follow up was done on 61 patients with 63 prostheses. The average constant score improved 45 points, pain decreased by 9 points, activity improved by 11 points, mobility improved by 18 points, and strength improved by 7.5 points. Though these results were not analyzed for statistical significance, clinical improvement was noted. Follow-up x-ray imaging showed no radiolucency, osteolysis, stress shielding or change in implant positioning. 7 complications were observed without significant implant loosening. 5 patients had lateral cortex fracture one first post-operative x-ray that healed by 2 months follow-up without intervention. 1 patient experienced a post-operative hematoma requiring drainage. 1 patient required open surgical release at 1 year follow-up due to persistent stiffness.

In 2015, Habermeyer et al. reported data from 78 patients who received TESS. Significant improvement in Constant-Murley relative percent, Constant-Murley absolute, pain, activities of daily living, ROM, active flexion, active abduction, and active external rotation were found. All of these findings were significant at P < 0.0001. Strength was the only metric to not show significant improvement. The reported complication rate was 12.8% with revision in 9% of the study population. 6 patients experience rotator cuff insufficiency with 3 undergoing reverse TSA and 1 undergoing pectoralis major transfer. 1 patient fell 2 months post-operatively fracturing the proximal humerus and underwent open reduction and internal fixation, and 1 patient experienced osteolysis of the greater tuberosity without loosening. No implant loosening or implant specific complications were observed.

In 2017, the longest outcome study currently available was published by Hawi et al. 43 patients were monitored for clinical and radiographic changes for a mean of 9 years. Patients received either TSA or hemiarthroplasty (HA) using the Eclipse model. The reported Constant-Murley score improved in categories of relative percent, absolute score, pain, activities of daily living, and ROM. Active abduction and active external rotation showed significant improvement as well, while strength did not. Radiographic assessment displayed lower bone mineral density at the superior aspect of the junction between the threaded cortical cage and the head component on anteroposterior radiographs of the humerus in 29.4% of patients. 14.7% of patients experienced upward migration of the humeral head. Incomplete radiolucency of <1 mm was observed in 2.3% of patients. No clinically significant loosening of humeral components was found. 1 patient had post-traumatic greater tuberosity resorption without impaired stability of the implant. 1 patient experienced a proximal humerus fracture after a fall at 7 weeks following the operation and underwent successful conservative treatment. 6 patients experienced post-operative rotator cuff deficiency. Management of these complications included 4 patients treated non-operatively, 1 underwent a pectoralis major transfer, and 1 underwent reverse TSA. The complication rate of this study was 9.3% overall. No humeral implant-related complications were noted in this study.

In 2018, Krukenberg et al. reported data on 105 patients with osteoarthritis who completed a minimum of 2-year follow up after implantation of Sidus (Biomet, Warsaw, IN, USA). Significant improvement in Constant-Murley Score, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES), Subjective Shoulder Value (SSV), active forward elevation, and active external rotation were reported. Outcomes were significant at p < 0.001. 90.4% of patients with TSA and 53.1% of patients with HA were very satisfied with their implants. Incomplete radiolucency was found in 19 patients. No evidence of osteolysis, anchor migration, or implant loosening were found. 4 patients had a lower bone density or atrophy around the humeral component. The complication rate was 6.7% without any revision procedures required. Complications included 1 patient with axillary nerve palsy, 2 patients with brachial plexus irritation, 1 with pectoralis major insufficiency, and 1 patient had a DVT post-operatively.
In 2018, Gallacher et al. published results from a 2-year follow-up study using Eclipse.50 100 shoulders in 86 patients were reviewed with a mean follow up of 35.4 months.50 Significant improvement was found in Oxford Shoulder Score, forward elevation, and external rotation.50 Reoperation rate was 5% with 4% prosthetic revision rate.50 Reoperations included 1 patient with an impingement of the biceps stump and 4 required reverse TSA due to rotator cuff insufficiency.50 Radiographically, a radius of curvature (ROC) deviation of more than 2 mm was found in 9 shoulders where the prostheses were considered to be oversized incorrectly.50 27 shoulders had at least a 3 mm ROC adjustment with 14 deviating in the superior-medial direction.50 22 shoulders had incomplete radiolucent lines and 8 had complete radiolucent lines without clinically significant loosening.50 1 shoulder showed metaphyseal osteolysis around the cage screw without instability.50

Beck et al. used TESS to conduct an 8-year follow up study on 31 shoulders in 26 patients.30 Significant improvement was found in flexion, abduction, constant score, and quick DASH and VAS scores (P < 0.001).30 Intraoperative complication rate was 0%. The postoperative complication rate was 9.7%.30 1 Patient had a peri-prosthetic humerus fracture at 76 months due to a fall that required revision to a stemmed component.30 1 patient had radiolucenty at the bone metal interface of the humerus without clinically significant loosening.30 1 patient had a designer fault of the glenoid component where disassembly of the liner from the metal-back base-plate had occurred and required revision.30 8-year implant survival was 93.5%, while reverse TSA is 93.1%.30 Stemmed TSA 10-year survival is between 92–97%.40

**Comparison Studies**

In 2013, Berth and Pap compared stemless and stemmed TSA with a 2-year minimum follow up.14 82 patients were divided into a stemmed group that received an Affinis (Mathys, Bettlach, Switzerland) implant or a stemless group that received a TESS implant.14 Groups were matched by age, gender, side, and length of hospital stay.14 Mean operation time was 91.5 minutes for the stemless group and 106.2 minutes for the stemmed group (P = 0.002).14 Estimated blood loss was 496.3 mL for stemless TSA and 593.4 mL for stemmed TSA (P = 0.026).14 Overall function studies of Constant Murley Score, DASH Score, and all directions of active ROM showed significant improvement after TSA (P < 0.001).14 Improvements in pain, activity, motion, strength, anteverision, abduction and external rotation were noted in both groups.14 No differences in pain, activity, motion, strength, total constant score, DASH, anteverision, abduction and external rotation were found between the two groups.14 There were 3 complications in the stemmed group consisting of a fissure of the greater tuberosity, post-operative hematoma, and 1 superficial wound infection. 2 complications were noted in the stemless group consisting of a fissure of the glenoid and one patient who experienced temporary incomplete brachial plexus neuropathy.14 No revision operations were required during this study.14

In 2014, Maier et al. compared stemless and stemmed shoulder prostheses in the treatment of osteoarthritis.51 24 patients were evenly divided into a stemless or stemmed TSA group. TESS was the stemless implant used and Aequalis (Tornier, Lyno, France) was the stemmed implant used.51 Pre-operatively, constant scores and mobility were significantly worse in the stemmed group.51 Postoperatively, both groups experienced significant improvement in constant scores.51 No other difference were noted in terms of pain, power, activity, mobility, flexion, abduction, external or internal rotation between the groups.51 No significant differences were found in terms of function or proprioception between the groups.51

In 2017, a study by Uschok et al. was published comparing Eclipse stemless and the Univers II (Arthrex, Naples, FL, USA) stemmed shoulders.37 15 stemless TSAs and 18 standard stemmed TSAs completed 2-year follow up.37 Of these patients, 14 stemless and 15 stemmed completed 5-year follow up.37 Eclipse saw improvements in ROM and constant score at 2 and 5 years. Active flexion improved at 2-years.37 Active abduction, external rotation, and pain improved at 5-year follow up.37 Patients who received Univers II saw improvements in constant score, pain, activities of daily living, ROM, active flexion, abduction and external rotation at 2 and 5-year intervals.37 Constant score improved between the 2 and 5-year follow up interval.37 Eclipse stemless implant and Univers II stemmed implant performed similarly without significant differences.37 Radiographic evaluation revealed decreased bone density near the humeral implant in 4 Eclipse and 10 Univers II implants though this difference was not statistically significant.37 Medial offset was significantly less for Eclipse implants.37 Lateral offset was greater in patients with Univers II implants, while Eclipse showed anatomic reconstruction.37 The complication rate for both groups was 13.8%.37 Eclipse had no humeral implant complications.37 Univers II had 1 fracture of the greater tuberosity causing traumatic loosening of the humeral component.37

In 2019, Rasmussen et al. compared stemmed and stemless TSA outcomes using the Nordic Arthroplasty Register Association dataset.52 Data from 761 stemless implants and 4398 stemmed shoulder arthroplasties between 2011 to 2016 were compiled.52 Mean follow
up was 28 months for stemless and 29 months for stemmed. 2.8% of the stemless TSA and 2.6% of the stemmed TSAs had to be revised.52 The survival rate at 1 and 6 years were 0.987 and 0.953 for the stemless implants, and 0.985 and 0.958 for the stemmed components, respectively.52 Survival rate differences were insignificant.52 The stemless TSA group was divided based on which device was implanted to examine survivability differences between Eclipse, Sidus, and Simpliciti.52 Eclipse was found to have a significantly lower 6-year cumulative survival rate when compared to Simpliciti and Sidus models (P = 0.02).52

Conclusions
The current literature supports the use of stemless TSA as a safe and effective technology. Theoretical advantages over stemmed components such as decreased blood loss, shorter operation times, less implant loosening, increased bone stock preservation, fewer periprosthetic complications, ease of postoperative revision, and improved anatomic reconstruction have been found.14,15,37,42,50,53–56 The authors predict stemless TSA will become more common in the coming years and surpass stemmed implants as the new standard for primary total shoulder arthroplasty. Increased use of stemless TSA will allow for improvements in technique and instrumentation to improve long-term outcomes.41 Further investigation of stemless total shoulder is required to ensure long-term outcomes are comparable to stemmed TSA.

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References
1. Edmonds A. Shoulder arthroplasty. In: Hand and Upper Extremity Rehabilitation. Amsterdam, the Netherlands: Elsevier Inc.; 2006:389–396.
2. Petroiccioli D, Bertone C, Marchi G. Stemless shoulder arthroplasty: a literature review. Joints. 2015;3(1):38–41.
3. Boileau P, Sinnerton RJ, Chuiard C, et al. Arthroplasty of the shoulder. J Bone Joint Surg Br. 2006;88(5):562–575.
4. Matti L, Mortera S, Arrigoni C, Castoldi F. Anatomic shoulder arthroplasty: an update on indications, technique, results and complication rates. Joints. 2015;3(2):72–77.
5. Farley KX, Wilson JM, Daly CA, Gottschalk MB, Wagner ER. The incidence of shoulder arthroplasty: rise and future projections compared to hip and knee arthroplasty. JSES Open Access. 2019;3(4):244.
6. Sloan M. Projected volume of primary and revision total joint replacement in the U.S. 2030 to 2060 [published online ahead of print 2018]. J Am Acad Orthop Surg. http://aaos-annualmeeting-presskit.org/2018/research-news/sloan_ftr/.
7. Christine C, Johnson Daniel J, Johnson Joseph N, et al. Nearly all shoulder replacement patients under age 55 return to sports. J Chem Inf Model. 2017;57(9):1689–1699.
8. Dillon MT, Chan PH, Inacio MCS, Singh A, Yian EH, Navarro RA. Yearly trends in elective shoulder arthroplasty, 2005–2013. Arthritis Care Res. 2017;69(10):1574–1581.
9. Hawi N, Tauber M, Messina MJ, Habermeyer P, Martetschläger F. Anatomic stemless shoulder arthroplasty and related outcomes: a systematic review. BMC Musculoskelet Disord. 2016;17(1):1–10.
10. Neer CS. Replacement arthroplasty for glenohumeral osteoarthritis. J Bone Joint Surg—Ser A. 1974;56(1):1–13.
11. Schmidutz F, Agarwal Y, Müller PE, Gueorguiev B, Richards RG, Sprecher CM. Stress-shielding induced bone remodeling in cementless shoulder resurfacing arthroplasty: a finite element analysis and in vivo results. J Biomach. 2014;47(14):3509–3516.
12. Fram B, Elder A, Namdari S. Periprosthetic humeral fractures in shoulder arthroplasty. JBJS Rev. 2019;7(11):e6.
13. Churchill RS, Athwal GS. Stemless shoulder arthroplasty—current results and designs. Curr Rev Musculoskeletal Med. 2016;9(1):10–16.
14. Berth A, Pap G. Stemless shoulder prosthesis versus conventional anatomic shoulder prosthesis in patients with osteoarthritis: a comparison of the functional outcome after a minimum of two years follow-up. J Orthop Traumatol. 2013;14(1):31–37.
15. Hawi N, Magosch P, Tauber M, Lichtenberg S, Habermeyer P. Nine-year outcome after anatomic stemless shoulder prosthesis: clinical and radiologic results. J Shoulder Elbow Surg. 2017;26(9):1609–1615.
16. Churchill RS. Stemless shoulder arthroplasty: current status. J Shoulder Elbow Surg. 2014;23(9):1409–1414.
17. U.S. National Library of Medicine. Arthrex Eclipse™ Shoulder Prosthesis. https://clinicaltrials.gov/ct2/show/NCT01790113. Accessed August 29, 2020.
18. U.S. National Library of Medicine. Simpliciti IDE Trial; Replacing the Humeral Head in Total Shoulder Arthroplasty. https://clinicaltrials.gov/ct2/show/NCT01390038. Accessed August 29, 2020.
19. U.S. National Library of Medicine. Sidus Stem-Free Shoulder IDE Study—Study Results. https://clinicaltrials.gov/ct2/show/results/NCT01878253. Accessed August 29, 2020.
20. U.S. National Library of Medicine. SMR Stemless Shoulder Arthroplasty Clinical Study. https://clinicaltrials.gov/ct2/show/NCT02679352. Accessed August 29, 2020.
21. U.S. National Library of Medicine. Easytech Reversed Shoulder System Clinical Study. https://clinicaltrials.gov/ct2/show/NCT03806842. Accessed August 29, 2020.
22. Maslow MD J, Wanner MD JP, Routman DO H, Byram MD I. The disappearing stem: the changing humeral side of shoulder arthroplasty. Int Congr Jt Reconsr. 2019:1–18.
23. Berth A, März V, Wissel H, Awiszus F, Amthauer H, Lohmann CH. SPECT/CT demonstrates the osseointegrative response of a stemless shoulder prostheses. J Shoulder Elbow Surg. 2016;25(4):e96–e103.
24. Denard PJ, Raisl P, Gobezie R, Edwards TB, Lederman E. Stress shielding of the humerus in press-fit anatomic shoulder arthroplasty: review and recommendations for evaluation. J Shoulder Elbow Surg. 2018;27(6):1139–1147.
25. Hernigou P, Quinmec S, Flouzat Lachaniette CH. One hundred and fifty years of history of the Morse Taper: from Stephen A. Morse in 1864 to complications related to modularity in hip arthroplasty. Int Orthop. 2013;37(10):2081–2088.
26. Romeo AA, Thorsness RJ, Sumner SA, Gobezie R, Lederman ES, Denard PJ. Short-term clinical outcome of an anatomic short-stem humeral component in total shoulder arthroplasty. J Shoulder Elb Surg. 2018;27(1):70–74.
27. Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants: requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand. 1981;52(2):155–170.
28. Khanuja HS, Vakil J, Goddard MS, et al. Cementless femoral fixation in total hip arthroplasty. J Bone Joint Surg Am. 2011;93(5):500–509.
29. Favre P, Henderson AD. Prediction of stemless humeral implant micromotion during upper limb activities. Clin Biomech (Bristol, Avon). 2016;36:46–51.
30. Beck S, Beck V, Wegner A, Dudda M, Patsalis T, Jäger M. Long-term survivorship of stemless anatomical shoulder replacement. International Orthopaedics (Sicot). 2018;42(6):1327–1330.
31. Schmidutz F, Sprecher CM, Milz S, Gohlke F, Hertel R, Braunstein V. Resurfacing of the humeral head: an analysis of the bone stock and osseous integration under the implant. J Orthop Res. 2015;33(9):1382–1390.
32. Beck S, Patsalis T, Busch A, et al. Long-term results of the reverse total evolutive shoulder system (TESS). Arch Orthop Trauma Surg. 2019;139(8):1039–1044.
33. Razfar N, Reeves JM, Langlohr DG, Willing R, Athwal GS, Johnson JA. Comparison of proximal humeral bone stresses between stemless, short stem, and standard stem length: a finite element analysis. J Shoulder Elb Surg. 2016;25(7):1076–1083.
34. Santos B, Quental C, Folgado J, Sarmento M, Monteiro J. Bone remodelling of the humerus after a resurfacing and a stemless shoulder arthroplasty. Clin Biomech (Bristol, Avon). May 2018;59:78–84.
35. Reeves JM, Langlohr GD, Athwal GS, Johnson JA. The effect of stemless humeral component fixation feature design on bone stress and strain response: a finite element analysis. J Shoulder Elbow Surg. 2018;27(12):2232–2241.
36. Habermeyer P, Lichtenberg S, Tauber M, Magosch P. Midterm results of stemless shoulder arthroplasty: a prospective study. J Shoulder Elb Surg. 2015;24(9):1463–1472.
37. Uschok S, Magosch P, Moe M, Lichtenberg S, Habermeyer P. Is the stemless humeral head replacement clinically and radiographically a secure equivalent to standard stem humeral head replacement in the long-term follow-up? A prospective randomized trial. J Shoulder Elb Surg. 2017;26(2):225–232.
38. Collin P, Matsukawa T, Boileau P, Brunner U,Walch G. Is the humeral stem useful in anatomic total shoulder arthroplasty? Int Orthop. 2017;41(5):1035–1039.
39. Comenda M, Quental C, Folgado J, Sarmento M, Monteiro J. Bone adaptation impact of stemless shoulder implants: a computational analysis. J Shoulder Elb Surg. 2019;28(10):1886–1896.
40. Kadum B, Hassany H, Wadsten M, et al. Geometrical analysis of stemless shoulder arthroplasty: a radiological study of seventy TESS total shoulder prostheses. Int Orthop. 2016;40(4):751–758.
41. Kadum B, Hassany H, Wadsten M, Sayed-Noor A, Sjödén G. Restoration of the joint geometry and outcome after stemless TESS shoulder arthroplasty. WJO. 2017;8(10):790–797.
42. von Engelhardt L V., Manzke M, Breil-Wirth A, Filler TJ, Jerosch J. Radiographic restoration of native anatomy: a comparison between stemmed and stemless shoulder arthroplasty. J Shoulder Elb Surg. 2019;28(8):1595–1600.
43. Nyffeler RW, Sheikh R, Jacob HAC, et al. Influence of humeral prosthesis height on biomechanics of glenohumeral abduction: an in vitro study. J Bone Joint Surg Am. 2004;86(3):575–580.
44. Nyffeler RW, Sheikh R, Jacob HAC, Gerber C. Stemless and short stem humeral components in shoulder arthroplasty. Bull Hosp Joint Dis. 2015;73:S145.
45. Denard PJ, Noyes MP, Walker JB, et al. Proximal stress shielding is decreased with a short stem compared with a traditional-length stem in total shoulder arthroplasty. J Shoulder Elb Surg. 2018;27(1):53–58.
46. Krukenberg A, McBirnie J, Bartsch S, et al. Sidus stem-free shoulder system for primary osteoarthritis: short-term results of a multicenter study. J Shoulder Elb Surg. 2018;27(8):1483–1490.
47. Athwal GS, Sperling JW, Rispoli DM, et al. Periprosthetic humeral fractures during shoulder arthroplasty. J Bone Jt Surg—Ser A. 2009;91(3):594–603.
48. Athwal GS, Sperling JW, Rispoli DM, Cofield RH. Periprosthetic humeral fractures after shoulder arthroplasty. J Bone Jt Surg—Ser A. 2004;86(4):680–689.
49. Kumar S, Sperling JW, Haidukewych GH, Cofield RH. TESS Group. Results of a new stemless shoulder prosthesis: radiologic proof of maintained fixation and stability after a minimum of three years’ follow-up. J Shoulder Elb Surg. 2010;19(6):847–852.
50. Huguet D, DeClercq G, Rio B, Teissier J, Zipoli B. Clinical and radiologic outcomes following total shoulder arthroplasty using arthrex eclipse stemless humeral component with minimum 2 years’ follow-up. J Shoulder Elb Surg. 2018;27(12):2191–2197.
51. Gallacher S, Williams HLM, King A, Kitson J, Smith CD, Thomas WJ. Are there differences between stemless and conventional stemmed shoulder prostheses in the treatment of glenohumeral osteoarthritis? Orthopedics and biomechanics. BMC Musculoskelet Disord. 2015;16(1):1–7.
52. Maier MW, Lauer S, Klotz MC, Büllhoff M, Spranz D, Zeifang F. The short-term survival of total stemless shoulder arthroplasty for osteoarthritis is comparable to that of total stemmed shoulder arthroplasty: a nordic arthroplasty register association study. *J Shoulder Elb Surg*. 2019;28(8):1578–1586.

53. Wilson JM, Holzgrefe RE, Staley C, et al. The effect of operative time on postoperative outcomes in total shoulder arthroplasty. *JSES Open Access*. 2019;3(4):244.

54. Wilson JM, Holzgrefe RE, Staley C, Karas S, Gottschalk MB, Wagner ER. Short to mid-term results of stemless reverse shoulder arthroplasty in a selected patient population compared to a matched control group with stem. *Int Orthopaed (Sicot)*. 2016;40(10):2115–2120.

55. Ballas R, Béguin L. Results of a stemless reverse shoulder prosthesis at more than 58 months mean without loosening. *J Shoulder Elb Surg*. 2013;22(9):e1–e6.

56. Teissier P, Teissier J, Kouyoumdjian P, Asencio G. The TESS reverse shoulder arthroplasty without a stem in the treatment of cuff-deficient shoulder conditions: clinical and radiographic results. *J Shoulder Elb Surg*. 2015;24(1):45–51.