Review Article

Stemless Reverse Shoulder Arthroplasty

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ABSTRACT

Since the Food and Drug Administration (FDA) approval nearly two decades ago, the indications for and utilization of reverse shoulder arthroplasty (RSA) have expanded considerably. Stemless RSA designs have been used in Europe since 2005, but have only recently been introduced in domestic Investigational Device Exemption trials. Potential advantages of stemless RSA are similar to those of stemless anatomic total shoulder arthroplasty, which may include fewer shaft-related complications, avoidance of stress shielding, bone preservation, and easier revision surgery. European data support similar outcomes between certain stemless RSA prostheses compared with that of stemmed RSA implants at early and mid-term follow-up. However, long-term outcomes remain to be seen and differences exist between the stemless RSA designs used in Europe and those being studied in domestic clinical trials. An understanding of the potential advantages and disadvantages of stemless RSA, differences between existing designs, and reported clinical outcomes is prudent for the safe and meaningful implementation of this new technology in the United States.

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The emerging availability of stemless humeral implants for reverse shoulder arthroplasty (RSA) in the United States warrants an overview of this new technology and a discussion of the available literature for surgeons considering its use. Over the past few decades, the evolution of the humeral stem design in RSA has paralleled that seen previously in anatomic total shoulder arthroplasty (aTSA).[1,2] Similar to the first generation of fixed-geometry humeral implants introduced by Neer 1951, the Grammont original reverse prototype used a monoblock humeral implant.[3,4] Implant modularity and variable geometry became the hallmarks of second and third-generation aTSA implants, respectively, which permitted modifications to better match native humeral anatomy.[2] In RSA, subsequent iterations of humeral implants have come to permit modifications of tray and insert thickness, offset, humeral inclination, and constraint to maximize muscle moment arms, avoid impingement, and optimize shoulder function. Fixation techniques have also changed over time from cemented to press-fit designs.

The latest generation of humeral implants is stemless designs. Introduced for aTSA in Europe in 2004 and approved by the Food and Drug

Administration (FDA) in 2016 for use in the United States, stemless designs are projected to outpace that of conventional stemmed implants in European markets by 2024.[5-7] While stemless humeral implants have also been used for RSA in Europe since 2005, they are only recently being evaluated in the United States through FDA Investigational Device Exemption (IDE) trials.[8,9] Early and mid-term outcomes from European studies have shown similar results between certain stemless designs and conventional, stemmed RSA.[7] Although a paucity of data is available on the systems currently being investigated for use in the United States, knowledge and understanding of this emerging technology is necessary as it becomes available to orthopaedic surgeons.

Modifications of Contemporary Humeral Stem Design in Reverse Shoulder Arthroplasty

In 1985, the Grammont original 'trompette' reverse prototype consisted of a cemented glenosphere and all-polyethene, monoblock humeral implant.[10] Early loosening and failure of the glenoid implant led to several design modifications seen in the second iteration of the Grammont design, the Delta III (DePuy International Ltd). Initially released in France in 1991, the Delta III implant would become the first FDA-approved reverse prosthesis for use in the United States. Compared with earlier RSA designs, the breakthrough success of the Delta III implant is attributed to improvements in glenoid implant design and fixation.[4,10] However, notable changes to the humeral implant were made as well, which laid the foundation for many modern-day RSA designs used today. The three-part humeral implant of the Delta III consisted of a conical diaphyseal humeral stem, a modular metaphyseal inlay block, and the polyethylene humeral insert. Initially, the diaphyseal stem and metaphyseal block were polished for cementation and later became available with hydroxyapatite coating for noncemented fixation. This classic medialized glenoid-medialized humerus (MGMH) 'Grammont' design used a nonanatomic, varus neck-shaft angle (NSA) of 155° to increase the acromiohumeral interval and deltoid tension.[11]

Subsequent changes in RSA humeral implant design have been rooted in efforts to optimize function and impingement-free range of motion (ROM), to avoid scapular notching, and to improve bone-preserving fixation, to minimize future challenges associated with revision surgery. Modifications of the RSA implant design and alterations in the surgical technique were popularized in response to the nearly ubiquitous and previously unseen phenomenon of scapular notching associated with the MGMH design. The concept of lateralization and a shift toward a more anatomic NSA (135°) of the humeral implant were two such modifications. Lateralization (or offset) of RSA involved shifting the center of rotation (COR) laterally from the face of the glenoid, compared with the MG design, and can be achieved on the glenoid side, humeral side, or both. The classification by Routman et al[12] categorized existing implant designs based on the amount of lateralization (or global offset) between the COR and the humerus and whether the implant lateralizes through the glenoid or humeral implant. The combination of these two variables results in four possible designs, with the Grammont-style prosthesis being the construct of reference: MGMH, lateralized glenoid and medialized humerus, MGLH (medialized glenoid and lateralized humerus), and lateralized glenoid and lateralized humerus. The introduction of lateralized humerus prostheses brought about humeral onlay designs, which use a flat, modular metaphyseal humeral tray that attaches to the stem on top of the humeral head cut surface. In contrast to the inlay designs characteristic of MGMH and lateralized glenoid and medialized humerus constructs, onlay humeral implants offer greater capacity to increase lateralization using the humeral tray and polyethylene insert and may allow adjustment of anteroposterior eccentricity of the humeral tray relative to the stem.

Various strategies have been implemented to improve humeral-sided fixation for noncemented, press-fit designs. Stem surface roughening, grit-blasting, plasma spray, and hydroxyapatite coating as well as porous scaffolds have been used to promote bony ongrowth and ingrowth, respectively. Changes in stem geometry have also been implemented to enhance stability against rotational torque forces, including the addition of proximal fins, distal flutes, and grooves. These advancements have allowed for the popularization of noncemented designs and the opportunity to achieve more proximal, bone-sparing fixation with shorter humeral stems. The latest generation of RSA implants focuses on bone preservation strategies to minimize potential challenges of revision surgery. One such example includes the advent of convertible systems that allows one to retain the humeral stem while replacing the modular anatomic humeral head for a reverse prosthesis humeral tray. Convertibility has previously been touted an advantage

of humeral onlay designs; however, several inlay stems now afford the same capability. Although convertible systems provide a relatively noninvasive, bone-sparing option for conversion of anatomic to RSA, the optimum stem position may be different for each construct.

The use of stemless humeral implants in aTSA has been another preparedness strategy to facilitate implant removal with minimal bone loss and allow for reinsertion and optimal positioning of an RSA humeral implant when necessary. The success of stemless humeral implants in aTSA has since led to the application of similar designs for RSA. These canal-sparing designs rely solely on metaphyseal or epiphyseal noncemented fixation and bony ingrowth or ongrowth properties for implant stability.[7] While stemless RSA has been used effectively in Europe for nearly two decades, differences exist between those prostheses and the implants being investigated in FDA trials. Furthermore, the potential effect of biomechanical differences between anatomic and RSAs should be considered with the adoption of this new technology for RSA.

Biomechanical Considerations with Stemless Reverse Shoulder Arthroplasty

To date, most of the biomechanical research on stemless humeral implants has investigated aTSA constructs. When considering the implications of this research in the setting of RSA, it should be recognized that the loads experienced by the humerus in RSA are different from aTSA because of fundamental differences in construct philosophy and design. Notable differences include increased constraint of the reverse articulation, increased deltoid lever arm, and the presence of torsional stress on humeral implant as it rotates as a fulcrum about a fixed COR.[13-15] Anatomic TSA recreates the native COR and maintains normal deltoid and rotator cuff force vectors that contribute to stabilizing compressive forces at the glenohumeral articulation. In RSA, nonanatomic reconstruction alters the force vectors of the deltoid and remaining rotator cuff about a medialized COR to optimize function in a pathologic shoulder. While RSA reduces the muscle forces required during shoulder function, it produces greater shear force and less compression at the implant articulation.[16,17] Owing to the increased shear forces produced in RSA compared with aTSA, available biomechanical data on stemless aTSA constructs cannot be extrapolated and reliably applied to stemless RSA.

Reliable fixation of noncemented humeral implants is dependent on primary implant stability to limit micromotion below the threshold of 150 μm for osseointegration. Favre and Henderson[18] demonstrated that 99% of a stemless aTSA implant (Sidus Stem-Free Shoulder, Zimmer GmbH) surface experienced subthreshold micromotion in a finite-element (FE) model of simulated physiologic activity. The percentage of implant surface area that experienced micromotion between 100 and 150 μm did, however, increase considerably when loaded (2 kg) in forward elevation and abduction. This may be relevant in RSA as forward elevation and abduction are the primary motions restored, which may have implications for early mobilization in overweight individuals if a stemless humeral implant is used. Micromotion of stemless humeral implants in RSA has not yet been specifically studied and should be prioritized as a topic of future biomechanical research.

Fixation of stemless implants is heavily dependent on the quality of bone density of the proximal humeral metaphysis. Spatial mapping of the bone density in this region has found stronger bone located in the periphery and medial calcar regions.[19] Although various designs exist, there is little evidence to determine how much this variability in bone density can affect fixation of stemless implant designs. Furthermore, different stemless designs use a variety of fixation features to improve implant stability.[20] Reeves et al[21] predicted how these design features affect bone stress and strain responses using aTSA FE model and found a trade-off between implant types. Stemless implants with central peg fixation were found to have the lowest potential for peri-implant bone resorption, which may optimize osseointegration, whereas implants with peripheral fixation had the greatest bone-implant contact area to enhance primary implant stability. Bachmaier et al[22] noted that in stemless RSA where the medialization of the glenohumeral COR induces higher postoperative shear forces and tilting effects on the humeral implant, the effect can be notable for implant loosening. Those authors compared a peripheral fixation with a central impaction fixation design in 25 cadaveric specimens and found that the peripheral fixation design provided higher peri-implant bone mineral density and bone volume fraction, which led to improved primary fixation.

A major impetus for the development of stemless humeral designs has been to minimize the risk of stress shielding. Standard-length diaphyseal fitting stems contribute to proximal bone resorption through stress shielding by redistributing load from native proximal humerus subcortical bone to distal regions of contact between the implant and the endosteum. FE analysis has shown stemless implants to more closely match the intact

stresses of proximal cortical bone at the expense of higher trabecular bone stress in an aTSA model.[23] Provided adequate fixation can be achieved, the more normal stress profiles of stemless implants should decrease risk of proximal stress shielding over traditional stemmed implants, which has been corroborated in clinical radiographic study.[24-26] Still, rates of stress shielding range between 0 and 40% with different stemless implants in aTSA clinical studies, in part, because of heterogeneity in reported definitions and length of follow-up.[24,25,27-29] FE modeling has also predicted how different stemless designs influence the location and concentration of stress experienced by surrounding bone.[21] This may affect not only the overall likelihood of stress shielding but the regions of the proximal humerus where stress shielding is most likely to occur. Medial calcar and greater tuberosity resorptive changes have predominated with anchor fin and hollow screw-type stemless aTSA designs, respectively.[26,28-30] While neither of these implants are available for use in RSA, the development, location, and effect of stress shielding with stemless RSA designs should be monitored going forward. Resorption of greater tuberosity and proximal humeral bone in RSA could lead to compromised external rotation function and instability due to loss of protective deltoid wrapping. In addition, stress shielding of the medial calcar could be potentiated by impingement and scapular notching.

Advantages and Indications

There have been several proposed advantages of stemless humeral implants in RSA similar to their use in aTSA. Press-fit, noncemented fixation within the epiphyseal and metaphyseal bone avoids instrumentation of the intramedullary canal and may allow for shorter operating time and lower intraoperative blood loss.[7,31] Preservation of humeral bone and potential reduction of metaphyseal stress shielding relative to traditional diaphyseal fitting stems may also facilitate implant extraction and simplify revision surgery when necessary.[7,8,32] Stemless implants may lower the risk of intraoperative humeral shaft periprosthetic fracture, but still risk fracture of more proximal metaphyseal bone.[8,32,33] If intraoperative proximal fracture occurs and compromises stemless implant fixation, bypassing with a short or standard-length stem may obviate the need for extensile exposure. Postoperative periprosthetic fractures that occur in metaphyseal bone around or just below well-fixed stemless implants may have a higher propensity for healing and have been successfully managed with sling immobilization without additional surgery.[9,31,33-35] In cases of altered anatomy, such as posttraumatic malunion, stemless RSA offers higher adaptability during implantation because the implant can be inserted independent of neck-shaft deformities and within a greater range of humeral osteotomy inclination angles.[7,8,31,32,36]

Stemless humeral implants can be used for many of the same diagnoses as traditional, stemmed RSA, including rotator cuff tear arthropathy; irreparable rotator cuff tears; osteoarthritis with at-risk rotator cuff, severe glenoid deformity; and posttraumatic arthritis.[9] Ideal indications include primary RSA with favorable metaphyseal bone stock and cases of posttraumatic malunion with metadiaphyseal deformity that cannot accept a stemmed implant.[9]

Disadvantages and Contraindications

A notable disadvantage of current stemless RSA designs is the limited modularity to increase humeral offset and deltoid tension. The addition of notable humeral offset through thicker humeral trays and polyethylene inserts likely imparts additional torque onto the bone-implant interface; however, the effect this has on primary implant stability has not yet been extensively studied. When adequate soft-tissue balance and stability cannot be achieved intraoperatively, implant removal and arthroplasty with a stemmed implant may be necessary. The same disadvantage may be of concern should postoperative instability require revision surgery.

Safe use of stemless humeral implants in RSA is predicated on the presence of adequate bone stock and ability to achieve stable press-fit metaphyseal fixation to avoid early aseptic loosening before osseointegration.[32,37,38] This may limit their utility in certain patient populations and the revision setting. In addition, secure fixation of lesser tuberosity osteotomy may be more challenging with the use of a stemless implant, and a large lesser tuberosity osteotomy harvest has the potential to affect primary implant stability. Perhaps the largest disadvantage of stemless RSA is the scarcity of long-term clinical data and a lack of published outcomes on the subset of stemless implants being investigated by FDA IDE trials.[8,32,33,38]

Relative contraindications for stemless RSA may include many patients with severe osteoporosis, large metaphyseal subchondral cysts, deficient metaphyseal bone stock, osteonecrosis, acute proximal humerus

fractures, pseudarthrosis, and metabolic bone disease.[8,9,39] Special consideration should be given before using a stemless RSA implant in the revision setting.[37]

Technical Considerations

Unlike traditional stemmed implants that are guided by the orientation of the intramedullary canal and allow for modularity of the tray/insert in relation to the stem, placement of a stemless humeral implant can be much less forgiving. For example, if a surgeon is attempting to properly balance the soft tissues when trialing a stemmed RSA, the distalization and lateralization of the humerus with respect to the glenoid can be altered by using an offset tray that can 'dial in' appropriate soft-tissue balance even if the tray is not perfectly centered over the longitudinal axis of the canal. Similarly, if increased tension is desired, the thickness of the tray and polyethylene can be increased to a substantial degree with the security of the stem helping to reduce concerns for excessive stress at the bone-implant interface. This is particularly useful in settings of bone loss such as severe deformity, revision surgery, or fracture scenarios. This modularity is unavailable with current stemless designs, and the limits of sizing can be affected by relatively less contact between the stemless implant and the host bone with increased concern for loosening.

Humeral Head Resection Height

When performing a humeral head resection, the goal is to remove as little bone as possible to permit sufficient access for glenoid instrumentation and properly restore soft-tissue balance once all implants are placed. In the setting of severe cuff tear arthropathy, a patient's soft tissues (ie, triceps, deltoid, and conjoint tendon) may be markedly tight because of years of proximal humeral migration. This can often make glenoid exposure difficult even after proper soft-tissue releases are performed. A larger humeral head resection is one solution to improve access in this scenario. With traditional stemmed implants, this resected bone can be 'built up' by increasing the humeral trays and polyethylene insert thickness that can add upwards of 20 mm of height to the humeral construct. This is counterintuitive if using a stemless implant where preservation of proximal humerus cancellous bone is paramount to the support and stability of the humeral anchor. As such, one must carefully assess the amount of bone taken during humeral resection and understand the limitations of the implant design being used to ensure that proper stability can be achieved.

Humeral Inclination

The humeral inclination of stemmed implants is predetermined by the NSA of the implant design, which guides accurate restoration of the desired inclination angle even if the humeral osteotomy is slightly off. Cox et al[40] examined stemless, short, and standard-stem aTSA implants and demonstrated that stemless implants were markedly more likely to be inserted in varus. At the time, these stemless implants were relatively new, but it illustrated the point that stemmed implants can aid surgeons in accurately restoring patient anatomy. In stemless RSA, valgus placement of humeral implants can lead to an increased risk of scapular notching as seen with the varus 155° NSA of the Grammont design. Because the placement of stemless humeral implants is so dependent on the angle and version of the humeral osteotomy, careful and accurate humeral resection is paramount. The use of preoperative planning software in shoulder arthroplasty has focused mostly on placement of glenoid implants because of limited bone stock of the glenoid vault; with the advent of stemless humeral implants, it will be equally important for the treating surgeon to carefully examine and measure the humerus as well.

Postoperatively, it can be difficult to assess the humeral inclination of an implanted stemless implant if the radiograph projection is not parallel to the base of the humeral implant. Beck et al[41] investigated this concern using a sawbone model and various angles of radiographic projections. The authors found that by measuring the radii of the minor (a) and major (b) axes of the ellipse as well as the observed inclination angle (ϕ) on a postoperative radiograph, the formula $\arccos\left(\sqrt{1-\left(\frac{a}{b}\right)^2}\times\cos(\phi)\right)$ could correctly determine the real inclination angle within 1.5°.

Placement of the Stemless Humeral Implant

Unlike stemmed implants that are seated within the canal and require greater preparation of proximal cancellous bone, stemless implants rely heavily on the press-fit impaction of the humeral anchor into the metaphysis. Owing to thinner cortices in this region of the humerus, the quality of the cancellous bone is much more important to the stability of the implant. Surgeons often describe the 'thumb test' in which the tactile feel of cancellous bone is determined to be of adequate quality for initial fixation of a stemless humeral implant. Conversely, sclerotic bone (ie, in the setting of osteonecrosis) can also cause difficulty in gaining good initial fixation at the time of impaction. Levy et al[34] reported

on two patients who sustained a nondisplaced fracture of proximal metaphyseal bone during impaction of a Verso stemless press-fit RSA; unlike the other stemless RSA implants discussed in the following section, this implant is more consistent with a short or mini-stem design. These were managed conservatively with success, but the concern for potential early loosening was noted by the authors. The force vector of stemless implant impaction is slightly more lateral than the axial-directed force applied when inserting a stemmed implant into thicker cortical bone; surgeons must be aware of this potential hazard and appreciate bone quality when impacting stemless RSA implants.

In any of these technical considerations, careful preoperative planning and scrutinization of humeral anatomy on preoperative CT scan can be helpful when placing stemless implants. Furthermore, intraoperative fluoroscopy can offer real-time feedback regarding osteotomy measurements and provide surveillance for any intraoperative fractures if desired by an adopting surgeon.

Stemless Reverse Shoulder Arthroplasty Implant Designs

There is considerable variability among the stemless RSA implants on the market. Differences in implant geometry and design features also exist between the stemless RSA implants that have been most extensively studied in Europe and those being investigated in FDA trials (Table 1).[33,37,42,43] The Verso Prosthesis (Innovative Design Orthopaedics, London, UK) and the Total Evolutive Shoulder System (TESS) (Zimmer-Biomet) are the two stemless designs with the longest track record in European markets. Both implants use a nonanatomic 150° to 155° NSA and an inlay humeral design that is most consistent with a traditional Grammont-style prosthesis. In addition, the Verso prosthesis is advertised as a stemless implant but has a design more consistent with a short or mini stem. Both the Verso system and TESS have standard stem length options, where the Verso stemmed option is a different implant and the TESS can accommodate a modular stemmed attachment. Neither of these implants is currently being investigated for use in the United States.

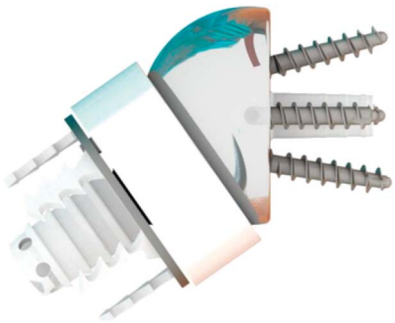
The Easytech Reversed Stemless (FX Solutions) and Shoulder Modular Replacement (SMR) Stemless Reverse (LimaCorporate) systems are currently in the final stages of FDA IDE clinical trials. Although these implants have already been available for use in Europe, limited clinical data have been published regarding their use. Compared with the Verso and TESS, the Easytech and SMR prostheses are more consistent with lateralized RSA designs. Easytech is the only available onlay humeral design and is intended for placement at a 145° NSA. Of the current stemless implants on the market, Easytech is also the only implant with a completely peripheral fixation design. The SMR Stemless Reverse system is an inlay humeral design inserted at an anatomic 135° NSA; a unique characteristic of this implant is the inverse bearing polyethylene glenosphere and metallic humeral insert.

Clinical Outcomes Based on Implant Design

Given the relatively new concept of stemless RSA, there are little long-term clinical data compared with traditional RSA designs. The Verso and TESS stemless systems have been in use the longest, and much of the published literature is focused on these two implants.[44] Because of the variability in implant design, it is important to critically evaluate the literature based on the implant being studied and not assume that clinical outcomes can be broadly applied across all stemless RSA designs.

Published data on early clinical outcomes have been favorable across most stemless implant designs. Two studies have examined the Verso implant at early follow-up within 3 years.[9,35] Both studies demonstrated improvement in patient forward elevation and abduction, with Atoun et al showing a statistically significant improvement in Constant scores (mean, 12.7 preoperatively to 56.2 postoperatively).[9,35] Neither study demonstrated any humeral radiolucency, early signs of loosening, or subsidence, with only as high as Grade 2 scapular notching noted in a minority of patients (9/68).[9,35] These good outcomes have been noted to continue into mid-term follow-up. Levy et al[34] found continued patient satisfaction, better postoperative ROM, and markedly improved Constant scores at an average of 4 years (range, 2 to 7 years). Radiographically, there remained no signs of humeral stress shielding or radiolucency, implant loosening, or subsidence. Virani et al[33] continued their follow-up to an average of 6.5 years and found that the results maintained notable improvement in postoperative functional scores with no signs of humeral or glenoid implant loosening. Humeral radiolucencies were noted in two patients after successful conservative management of metaphyseal periprosthetic fracture; otherwise no evidence of stress shielding was

Table 1. Current Stemless Reverse Shoulder Arthroplasty Prostheses and Associated Design Features

Implant	Design Features
	***Verso*** **(Innovative Design Orthopaedics, London, UK)** • Advertised as a stemless implant. • Design more consistent with a short stem. • Humeral implant has three hydroxyapatite-coated tapered fins for noncemented press-fit fixation.[37] • Designed with a 155° NSA • Uses an inclined 10° polyethylene liner to help reduce medial impingement.
	***Total Evolutive Shoulder System (TESS)*** **(Zimmer-Biomet, Warsaw, IN, USA)** • Short reverse corolla noncemented metaphyseal-epiphyseal inlay CoCr implant • Six wings are designed to provide rotational stability • Ti plasma spray and hydroxyapatite coating.[35] • Designed for 150-155° NSA • Stemmed option available
	***Easytech Reversed Stemless*** **(FX Solutions, Viriat, France)** • Anchor base design for peripheral fixation within the cortical rim. • 'Christmas tree' like peripheral pegs are plasma-sprayed Ti with hydroxyapatite coating to support the onlay design tray. • Designed for 145° NSA, more consistent with lateralized reverse TSA designs.[40] • Only stemless RSA with a completely peripheral fixation design.[41]
	***Shoulder Modular Replacement (SMR) Stemless Reverse*** **(LimaCorporate, San Daniele del Friuli, Italy)** • Trabecular Ti humeral core implant with a proximal ring and two radiating fins to central peg, available in 8 sizes. • Impacted directly into the metaphysis with an inlay design placed at a 135° NSA. • 5° CoCr humeral liner available in 40 mm or 44 mm to match the respectively sized polyethylene glenosphere.[41]

noted. The authors, however, did note an increase in the incidence of scapular notching at 23.5%.

The TESS implant has also demonstrated early success, with short-term evidence showing notable improvement in patient satisfaction, functional outcomes, and postoperative ROM.[36,37,44,45] Early scapular notching was slightly higher in the TESS implant, ranging from 13 to 30% of cases; the incidence of humeral radiolucent lines was not reported in these studies.[36,37,45] More noteworthy was early glenoid loosening noted in two of the studies (seven of 72 patients in total) and one study showing early humeral loosening in a patient who underwent stemless reverse arthroplasty as a revision procedure.[37,45] Despite these findings, mid and long-term follow-up studies have been promising; Beck et al reported favorable long-term survivorship of 93% at 8.5 years comparable with conventional stemmed implants.[38,46] The incidence of scapular notching was noted to increase with this longer duration of follow-up, and many authors have proposed continued evaluation of a more anatomical NSA to reduce these occurrences.[36,37,45]

Schoch et al[8] reported the only published data on the SMR Stemless Reverse implant with 2-year clinical and radiological outcomes comparable with stemmed implants. Constant scores showed notable improvement (from 35 to 74). Radiographically, the authors did note radiolucency around the humeral implant in nearly a quarter of the cases with complete loosening of one humeral implant. Interestingly, the authors stated that the patient with evidence of complete humeral loosening did well with no need for revision.

The only available data on the Easytech Reversed Stemless implant was recently published by Nabergoj et al[47] who reported on 115 patients with a minimum 2-year follow-up from a prospective multicenter trial. Constant scores and subjective shoulder values showed notable improvement from 33 to 62 and 27 to 78, respectively. Radiographically, scapular notching was observed in 24% patients, humeral loosening in 4% (5 patients), and glenoid loosening in 4% (4 patients); humeral radiolucency was not independently reported. Concerningly, the authors reported a complication rate over 17% with eight implant revisions. Indications for implant revision included three dislocations, three humeral implant displacements (two secondary to fall), one case of combined glenoid and humeral loosening, and one periprosthetic humerus fracture.

When pooling the available data across all designs, stemless RSA has performed favorably compared with traditional implants. Liu et al[48] pooled 324 stemless RSA patients from seven studies with early and mid-term results (mean follow-up 44 months) demonstrating notable improvements in ROM and functional scores; no evidence of humeral loosening; and complication and revision rates of 12% and 5%, respectively. Kostretzis et al[49] echoed these findings in their systematic review of 517 patients from 13 studies with mean follow-up ranging between six and 102 months, citing complication and revision rates both of 7%. Of those revisions, only 1.4% were related to humeral implant issues. The authors concluded that at mid-term follow up, stemless reverse implants resulted in clinical and radiological outcomes equivalent to their stemmed counterparts. Ajibade et al[44] evaluated 10 studies with a total of 437 stemless RSAs followed for a range of six to 102 months and demonstrated similar findings of functional improvement with a relatively low rate of complications. It should be noted that the participants in all of these systematic reviews had only TESS and Verso implants because of limited published data on other implant designs.

Complications

The complications seen with stemless RSA are similar to those seen with traditional RSA implants, regardless of humeral implant fixation. Scapular notching is a common radiographic finding in RSA, particularly in Grammont-style designs with varus 155° NSA compared with lateralized designs with a more anatomic NSA. Because many of the early stemless reverse designs have embraced the 155° NSA, there is a correlating rate of scapular notching between 0 and 96%.[8,45] This wide range is likely because of the greater variability in the placement of stemless implants opposed to stemmed designs bound by the limits of implant within the canal.[50] Scapular notching, however, does not always have a clinical effect, and although its rates can be high, its effects on revisions are markedly lower.

Overall rates of complications in stemless RSA have remained fairly consistent across studies. Pooled analyses have described complication rates between 6.5% and 13.7%.[7,44,48,49] The TESS implant, which remains the most studied design, has an overall complication rate ranging from 1% to 13%.[36,37,45] Variation in complication rates reported can be because of variation in surgical indications. This is especially true when it comes to the most common complication: instability. Instability with dislocation is the most commonly reported complication in RSA overall, with rates ranging from 1.5% to 31%.[51] Not surprisingly, it is also the most frequently

reported complication in stemless RSA.[44,48,49] Many of these dislocations occur in stemless RSAs performed for fracture or other indications with humeral bone loss that can result in loss of proper deltoid tension.[8,44,45] Because of limitations in humeral implant height positioning and the need for adequate fixation in the metaphyseal bone, instability may be more likely to occur.[44]

Another complication of concern is periprosthetic fractures. As mentioned before, impaction of the humeral implant into metaphyseal bone with thinner cortices can result in intraoperative fractures. Fortunately, such fractures described in the literature have done well with nonsurgical treatment after implantation.[34,46] Postoperative periprosthetic fractures in the setting of trauma can occur with both stemless and traditional RSA designs.[9,33,34] However, the periprosthetic fracture pattern and revision fixation options with stemless implants are different than traditional implants; certain fractures may require a greater need for revision of humeral implants if limited proximal bone fixation is compromised when they occur. As the use of stemless implants increases, the evolution of how to treat postoperative fractures of the humerus will follow.

Estimated rates of complications requiring revision after stemless RSA range between 3.8% and 5.8%.[7,9,35,49] In the largest systematic review to date, this revision rate equated to a survival rate of 96% at an average of 42 months.[49] Despite the uniqueness of humeral fixation in stemless RSA and the theoretical concern for loosening, many studies have shown limited humeral-associated causes of revision. In their systematic review of 324 cases, Liu et al[48] found that only three of 17 revisions were because of early humeral implant displacement (1%). Similarly, Kostretzis et al[49] reviewed 517 cases with only three reports of humeral aseptic loosening causing revision (0.7%). Finally, Ajibade et al[44] found only one of 437 cases requiring revision for a loose humeral implant, accounting for 0.2% of cases. Revision rates in the studies reviewed in that analysis ranged from 0% to 25% overall. These findings are promising for stemless humeral RSA as it seems that the reasons for revision are similar to those of stemmed implants.

Conclusion

Stemless RSA has been used in Europe for nearly two decades with comparable mid-term clinical outcomes, complications, and revision rates with traditional stemmed implants. There is considerable variability in the design of existing stemless prosthesis, and limited data are currently available on the implants being investigated for use in the United States. Use of stemless implants in RSA requires unique technical considerations and careful humeral head resection to ensure accurate implant placement and adequate construct stability because of the limited modularity of these implants. As more studies with longer follow-up are conducted, appropriate indications and differences between various implant designs will continue to become clearer.

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