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Convertible-platform shoulder arthroplasty

Shayne R. Kelly, DO[a], Daniel C. Touhey, BA[b], Matthew J. Smith, MD[a,*]

[a]Department of Orthopaedic Surgery, University of Missouri, Columbia, MO, USA
[b]School of Medicine, University of Missouri, Columbia, MO, USA

A R T I C L E I N F O

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Background: Shoulder arthroplasty has become an increasingly common procedure used to treat degenerative, inflammatory, and traumatic conditions of the glenohumeral joint. With a significant increase in primary anatomic and reverse total shoulder arthroplasty, revision procedures have likewise increased. Updates in shoulder arthroplasty have allowed for the convertibility of implants, which allows for the retention of both glenoid and humeral components during revision surgery. This review aims to highlight the epidemiology, indications, and outcomes of convertible-platform total shoulder arthroplasty procedures.
Methods: A review of the current literature surrounding convertible-platform shoulder arthroplasty was completed to highlight the advantages and disadvantages of commercially available instrumentation and implant systems as well as their outcomes.
Discussion: Leading causes of shoulder arthroplasty revision surgery include glenoid failure, implant instability, and rotator cuff dysfunction. Variations in implant design between inlay and onlay humeral components and metal-backed glenoid components are important considerations at the time of revision surgery. Advantages of convertible-platform systems include increased efficiency and decreased complications during revision procedures as well as shorter recovery, lower cost, and better functional outcomes. Limitations of convertible systems include poorly positioned components during the index procedure, excessive soft-tissue tensioning, and problems associated with metal-backed glenoid implants. Changes in arm length have also been documented. These findings indicate the benefit of additional research and design to improve the effectiveness and utility of convertible-platform shoulder arthroplasty systems.

Shoulder arthroplasty has become a common procedure used to treat degenerative, inflammatory, and traumatic conditions of the glenohumeral joint. In a national database study performed from 2012 to 2017 by Best et al, there was a 32% and 164% increase in anatomic total shoulder arthroplasty (aTSA) and reverse total shoulder arthroplasty (rTSA), respectively.[3] Other studies performed in the last decade have shown a more than 200% increase in primary shoulder arthroplasty procedures and an increase of more than 300% in revision total shoulder arthroplasty procedures (revTSA).[8,18] As the indications expand for primary aTSA and rTSA, coupled with an active, aging population, it is likely that we will see the number of revTSA continue to increase in the years to come. This has led to an increased interest in improving outcomes related to revTSA and the advent of convertible shoulder arthroplasty systems which allow for retention of both humeral and glenoid implants. The purpose of this article is to review the epidemiology and indications for revTSA as well as to review the types and outcomes associated with convertible shoulder arthroplasty systems.

Epidemiology and indications for revision

Revision rates of aTSA and rTSA range from 8% to 12.6% with each of them having different mechanisms of failure.[1,9,24,26,34,37,45] Revision rates of shoulder hemiarthroplasty (HA) are often higher than aTSA and rTSA likely within an earlier timeframe.[10] Failure of HA is most commonly due to glenoid erosion, rotator cuff dysfunction, or due to tuberosity complications in the fracture setting, whereas aTSA and rTSA have differing causes of complication and failure.[11]

Pareda et al conducted a recent international database study, which revealed that aTSA had complication and revision rates of 10.7% and 5.6%, respectively (Fig. 1).[30] In comparison, the

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*Corresponding author: Matthew J. Smith, MD, Clinical Professor of Orthopedic Surgery, Outpatient Medical Director Department of Orthopedic Surgery, Department of Orthopaedic Surgery, Missouri Orthopaedic Institute, University of Missouri, 1100 Virginia Ave, Columbia, MO 65212, USA.

E-mail address: smithmj@health.missouri.edu (M.J. Smith).

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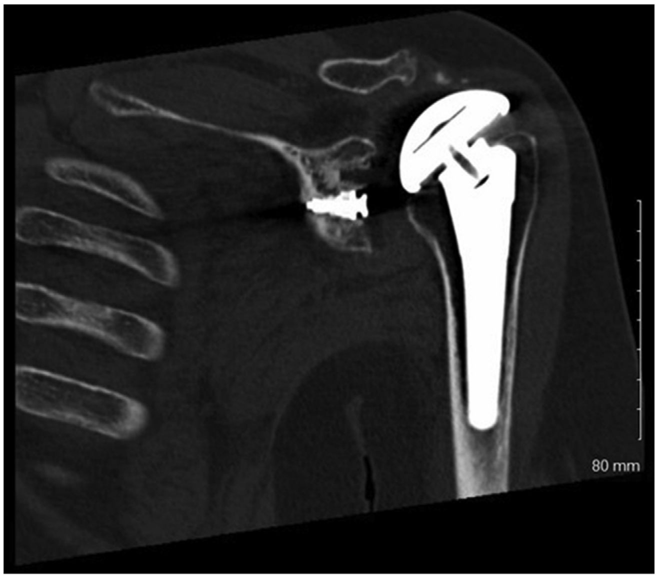

Figure 1 Left shoulder coronal CT of an anatomic TSA failed secondary to rotator cuff dysfunction. *CT*, computed tomography; *TSA*, total shoulder arthoplasty.

complication and revision rates for rTSA were 8.9% and 2.5%, respectively. The most frequently observed complications in aTSA were rotator cuff tear/subscapularis failure, aseptic glenoid loosening, and infection, whereas acromial/scapular pain or fracture, instability, and pain were the most common complications in rTSA. In regard to rotator cuff dysfunction in aTSA, a study performed by Young et al showed that 55% of their shoulder arthroplasty patients had signs of rotator cuff dysfunction at 15 years of follow-up.[46] Other causes of failure such as infection, fracture, pain, and stiffness may also contribute to revision surgery including tuberosity-specific complications including resorption, malunion, or nonunion when shoulder arthroplasty is used in the setting of fracture care.[9,24,26,34,37,46]

Convertible shoulder implants

Prior to revision surgery, it is important to use operative reports and imaging to identify if the implant is a convertible system capable of being retained. Imaging, including X-rays, computed tomography scans, and magnetic resonance imaging scans may be used to assess the stability and positioning of the implant and to rule out any loosening, osteolysis, or other concerns that may require removal of the implant. It is important to note that even when revising a convertible implant, studies have shown that nearly 25% are unable to be retained at the time of surgery due to reasons such as overstuffing, loosening, or excessive soft-tissue contracture.[6,31,42]

If a humeral component is noted to be convertible, it is important to consider the type and position of the implant prior to revision surgery (Table I). Humeral components can be categorized based upon the position they are implanted in relation to the proximal humeral osteotomy. The two primary categories are onlay and inlay humeral components, while recent implants have been created to provide an at-the-surface variation. A humeral onlay component places the stem into the bone, while the humeral tray and polyethylene line sits atop the humeral osteotomy (Fig. 2). An onlay humeral component is beneficial in that it preserves proximal humeral bone stock including the tuberosities, can improve lateralization of the humerus, deltoid wrapping, range of motion, and is debated as being technically less challenging.[2,13,32,43] In contrast, a humeral inlay component often reams out the proximal humeral metaphysis to accept an implant that sits below the level of the osteotomy (Fig. 3). An inlay humeral component may allow for a more anatomic reconstruction with increased bony contact and ingrowth, improved shoulder contour with less humeral lengthening, less challenging subscapularis repair, and a reduced risk for scapular spine fractures and neurologic injuries.[7,12,14,20,25] At-the-surface humeral components have a theoretical combination of both inlay and onlay stems with the humeral articular surface resting at the level of the humeral osteotomy (Fig. 4).

Although the difference in component type are debated at length, a recent study comparing radiographic outcomes between inlay and only components showed that there was no difference in humeral distalization or glenohumeral offset.[27] It was also noted that 66% of inlay components were actually placed above the level of the osteotomy. This demonstrated that although onlay systems are always placed above the level of the proximal humerus osteotomy, inlay components may vary and can be placed below, at or above the osteotomy site. Ultimately, it is important to take into consideration the level of the humeral osteotomy, the type and position of humeral implant used, and the potential soft-tissue implication that these variations have in a revision setting.

We believe it is important to briefly mention the glenoid component with respect to possible conversion. Although options are more limited, modular metal-backed glenoid (MBG) components may also allow for a simple exchange of components in a revision setting without removal of the main glenoid component or fixation (Table I). In aTSA, it allows for an exchange of the polyethylene component, while in a revision to a rTSA, a glenosphere can be placed onto the MBG. These convertible systems potentially allow for flexibility in revision surgery and can improve operating room efficiency while reducing potential complications related to removal of humeral or glenoid components, but they also have limitations in their uses.

Advantages of convertible implants

Convertible systems for total shoulder arthroplasty offer several distinct advantages over traditional implant design. Most importantly, modular systems consist of a humeral stem and glenoid base plate that may be retained at the time of reoperation providing for more efficient revision procedures with fewer complications. These systems allow for conversion from an HA to an aTSA to an rTSA (Figs. 5 and 6), which is often the more suitable option in cases that may not be amenable to aTSA revision. Conversion to rTSA is specifically appropriate in the setting of massive rotator cuff tear, instability, or glenoid component loosening, which again are among the most cited reasons for shoulder arthroplasty revision (Figs. 1 and 7).[6,15,16,21]

Intraoperative complications are significantly lower with convertible systems compared to conventional revision procedures that necessitate the use of revision implants, augments, and bone graft.[15] Extraction of the humeral component is traditionally the most common source of complications due to a stem that may be well-incorporated, well-positioned, which is often not the indication for revision.[5,6,15,17,28] In a multicenter retrospective analysis involving 102 patients, Crosby et al found that 15% of revision procedures involving humeral stem extraction experienced intraoperative complications compared with 0% of procedures in which the humeral component was retained.[6] Complications that arise include nonunion of the cortical osteotomy window, bone loss, dislocation, nerve injury, and iatrogenic fracture.[41,45] In addition to excessive soft-tissue trauma, fractures during explant occur as often as 24%.[38] In a systematic review of seven studies involving 236 shoulder

Table I
List of convertible shoulder arthroplasty systems.

Company	Convertible humeral system	Type humeral stem	Convertible glenoid system
Arthrex	*	*	Univers Reverse
Catalyst	Archer	Inlay	*
Depuy Synthes	Global Unite	Inlay	*
	Inhance	At surface	
DJO	Altivate	Inlay	*
Exactech	Equinoxe	Onlay	*
FH	Arrow	Onlay	Arrow
FX Solutions	Humeris	Onlay	*
	Humelock v135	Inlay	
	V135 Mini	Inlay	
LIMA	Prima		SMR TT
Link	Embrace	Onlay	Embrace
Medacta	Shoulder System	Onlay	*
Integra	Titan	Inlay	*
Shoulder Innovations	Inset	Inlay	*
Smith & Nephew	AETOS	Inlay	*
Stryker/Tornier	Ascend Flex	Onlay	*
	Perform	Inlay	
	ReUnion	Onlay	
Zimmer Biomet	Anatomical Shoulder	Onlay	Comprehensive
	Comprehensive	Onlay	
	Identity	Inlay/Onlay	
	TM Reverse	Inlay	

*Company does not currently offer this type of convertible implants.

revision cases, Kirsch et al additionally found that stem exchange was associated with an increased risk for reoperation.[21]

Revision surgeries using convertible implant systems are shorter in duration and involve less blood loss.[4,6,16,21,22,31,33,36,38,40,41,44,45] Kirsch reported a greater mean difference of 260 mL in blood loss and 62 minutes of operative time with humeral stem exchange over retention.[21] Crosby likewise found that conversion-based revision procedures led to 200 mL less mean blood loss and 65 minutes less operative time than with humeral stem exchange.[6] Longer surgical times with humeral component exchange are due largely to the technically demands of the extraction procedure. Several authors have described methods for stem removal including a challenging medial osteotomy under the insertion of the pectoralis.[4,33,36] These techniques have all shown to contribute to lengthy surgeries even under the direction of expert surgeons.

Shorter recovery times, better functional outcomes, and lower cost are also associated with the use of modular implant systems. Humeral osteotomy involved with stem extraction necessitates immobilization, which increases recovery time and may lead to longer hospital stays.[4,6,15] Numerous studies have demonstrated that conversion systems do not compromise functional outcomes in comparison to traditional revision procedures and provide the advantages of reduced complication and reoperation rates.[6,27,33,36] Crosby found that implant retention not only leads to near-equivalent functional outcome scores but also improved range of motion with active external rotation compared to stem exchange.[6] The cost of conversion systems is, on average, similar to that of traditional implant systems, which lends additional support for their use as they provide the added benefits of less blood loss, faster surgeries, and fewer complications.[6]

Limitations of convertible implants

Convertible implant systems are not without limitations. A poorly integrated or poorly positioned humeral component will continue to present similar problems at the time of revision, and the use of a convertible system during the index procedure does not guarantee the humeral stem may be retained during revision. In a recent retrospective analysis of 40 shoulder arthroplasty revisions involving convertible modular systems, Theelen et al found that 27.5% of the procedures necessitated humeral stem extraction (excluding patients with stem loosening and periprosthetic joint infections).[36] The study notes that the most common reasons for revision in convertible-based procedures is excessive tissue tensioning that makes reduction of the rTSA impossible or causes limited range of motion. Theelen goes on to explain that an insufficient humeral head resection during the primary procedure leads to increased stress on the rotator cuff and subsequent cuff dysfunction.[36]

Figure 2 Right shoulder AP X-ray demonstrating an onlay reverse total shoulder arthroplasty (Tornier Ascend Flex; Tornier, Bloomington, MN, USA) with humeral tray and liner articulating above the level of resection (yellow line).

Excessive soft-tissue tensioning is a common problem among conversion systems and precipitates impaired range of motion, tissue contracture, and inability to retain the humeral component.[36,41,42,45] Kany et al found that 24% of modular revision cases required humeral stem exchange due to proximal malpositioning and excessive stress on the glenosphere.[16] Reuther et al likewise reported that 23% of revisions involving platform systems could not be converted due to overstuffing.[31] Werner et al found that 13 of 37 revision cases with modular implants required stem extraction due to excessive soft-tissue contracture or loosening that prevented retention.[42] These findings reveal the importance of proper stem positioning during the primary procedure not only to ensure initial incorporation of the implant but also to allow for adequate reduction of the rTSA prosthesis if a revision must be performed.

While MBG components may provide for simple polyethylene exchange in aTSA and conversion to glenosphere during revision to rTSA, complications are a well-documented cause of failure in

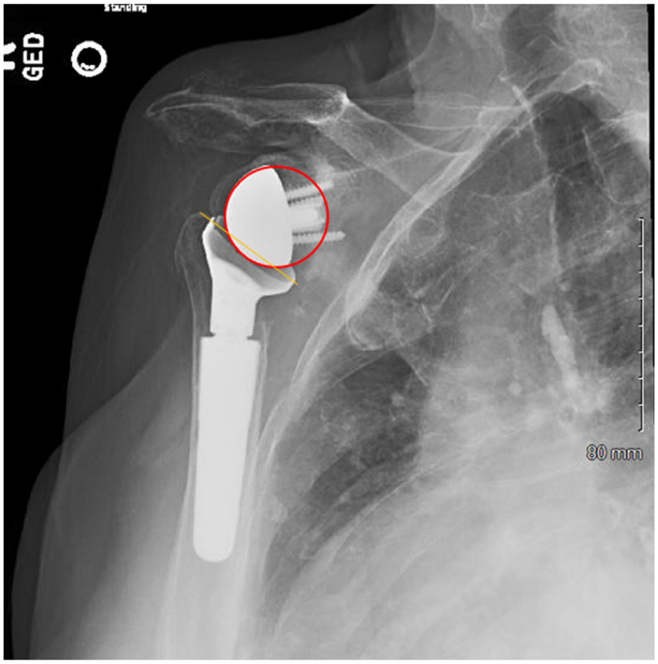

Figure 3 Right shoulder X-ray demonstrating and inlay right reverse total shoulder arthroplasty (Lima SMR Humeral component; Lima Corp., Arlington, TX, USA) A with metaphyseal portion reamed within bone and the articulation occurring below the level or resection (yellow line).

shoulder arthroplasty.[19,29,35,41] In a recent systematic review of more than 1500 conventional MBG components, Papadonikolakis et al reported a revision rate of 14%, more than three times that of all-polyethylene counterparts.[29] Although 38% of these revisions were due to loosening, the majority of cases were for additional reasons including component fracture, screw breakage, component dissociation, polyethylene wear, metal wear, and rotator cuff tear. Polyethylene wear with metal wear of the glenoid component were likewise noted by Tauton et al following 25% of 83 aTSA procedures, while glenoid component loosening was noted after 40% of cases.[35]

Updates have been made to the conventional MBG design including a trabecular surface that allows for bony ingrowth and provides structural and functional properties similar to bone. A recent systematic review by Kim et al reported significantly lower loosening and failure rates with modern MBG over conventional design as well as improved range of motion and clinical scores.[19] However, modern designs are not free of complication. Watson et al recently reported a 25% rate of radiographic metal debris or osteolysis at a minimum 2-year follow-up in a series of 36 patients.[39] Although no cases of loosening were reported and the modern MBG implant appears to provide adequate fixation, complications were severe when they occurred. These accounts highlight the ongoing challenges MBG implants continue to present.

Finally, attention should be given to the risk for changes in arm length that may occur when converting to rTSA from aTSA or HA. rTSA compensates for rotator cuff insufficiency by recruiting deltoid fibers and restoring tension to the muscle, which may lead to changes in arm length.[42] Lädermann et al reported a mean arm lengthening of 2.7 cm following primary rTSA in 41 patients, which correlated with postoperative neurological injury.[22] In a subsequent study of 183 patients, Lädermann found a mean lengthening of 1.6 cm did not correlate with changes in functional outcome.[23] Werner et al reported a mean lengthening of 2.6 cm in 14 of 37 patients undergoing conversion led to no mechanical or neurological complications.[42] Werner noted, however, that excessive arm lengthening following humeral adapter insertion may nevertheless result in neurological complications as well as fatigue fractures and glenoid baseplate loosening.[42] These findings further underscore the significance of achieving appropriate proximal muscle tensioning and balance during primary implantation and revision to ensure optimal long-term outcomes.

Figure 4 Left shoulder AP X-ray demonstrating a at-the-surface reverse total shoulder arthroplasty (DePuy Inhance; Raynham, MA, USA) with humeral tray and liner allowing for articulation at the level of the resection (yellow line).

Conclusion

As the number of revTSA increase over time, it is important to understand the indications for revTSA and the options and outcomes of convertible shoulder implant systems. A well-functioning anatomic total shoulder that goes on to develop rotator cuff dysfunction can potentially be easily converted to a reverse arthroplasty. However, in other cases of failure, it is important for convertible systems to have significant modularity and size options for balancing soft tissue while maintaining stability. Although convertible systems may have the ability to decrease intraoperative morbidity while improving efficiency and outcomes in the revision setting, they also have their limitations. Further research and design may be beneficial to improve the efficacy of these systems including long-term follow-up and analysis.

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Figure 5 Right shoulder AP X-ray demonstrating hemiarthroplasty for fracture.

Figure 6 Right shoulder AP X-ray demonstrating a converted hemiarthroplasty to reverse with stem retention and entire metaphyseal poriton placed below initial anatomic neck.

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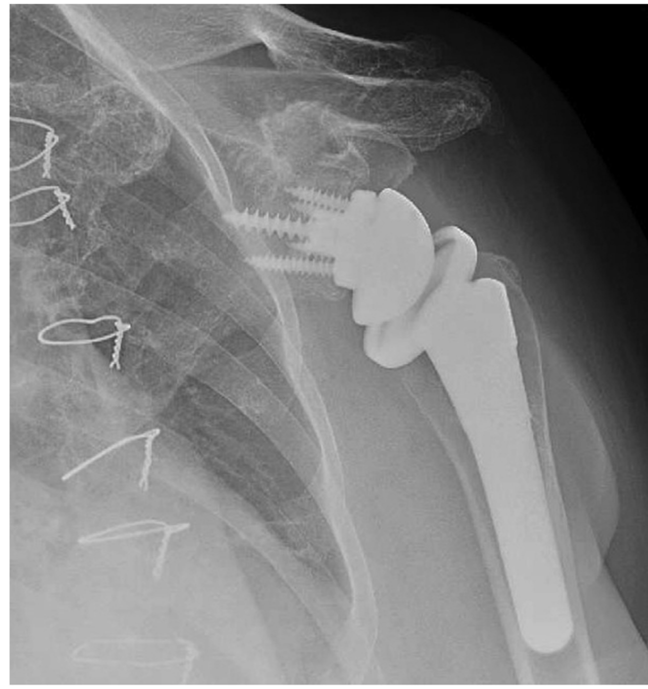

Figure 7 Left shoulder AP X-ray demonstrating left shoulder in Figure 1 conversion to rTsa with stem retention (Biomet, Warsaw, IN, USA).

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