Anatomic glenohumeral arthroplasty: State of the art

Piotr Lukasiewicz a, Edward McFarland a, Jeffrey D. Hassebrock b, Timothy P. McCarthy b, Stephen M. Sylvia b, Eric C. McCarty b, Stephen C. Weber a,*,

a Division of Shoulder Surgery, the Department of Orthopaedic Surgery, The Johns Hopkins University, 733 N Broadway, Baltimore, MD 21205, USA
b The University of Colorado School of Medicine, 13001 E 17th Pl, Aurora, CO 80045, USA

ARTICLE INFO

Keywords:
Shoulder arthroplasty
Humeral stem
Metal backed glenoid
Short stem humeral component
Stemless humeral component
Augmented glenoid
Patient specific guides

ABSTRACT

Anatomical total shoulder arthroplasty in its modern form where it reproduces the normal shoulder has been utilized clinically for more than half a century. As the technology and the designs have changed to recreate the humeral and glenoid sides of the joint, the sophistication of design has resulted in the growing number of cases annually worldwide. This increase is due in part to the increasing number of indications that the prosthesis can treat with successful results. On the humeral side, there have been design changes to better reflect the proximal humeral anatomy, and humeral stems are increasingly placed safely without cement. Platform systems which allow conversion of a failed arthroplasty to a reverse configuration without stem extraction is another design change. Similarly, there has been increasing utilization of short stem and stemless humeral components. Extensive experience with shorter stem and stemless devices, however, has yet to demonstrate the purported advantages of these devices, as recent studies have demonstrated equivalent blood loss, fracture rates, operative times, and outcome scores. Easier revision with these shorter stems remains to be definitively established, with only one study comparing the ease of revision between stem types. On the glenoid side, hybrid cementless glenoids, inlay glenoids, cementless all-polyethylene glenoids, and augmented glenoids have all been investigated; however, the indications for these devices remain unclear. Lastly, innovative surgical approaches to implanting shoulder arthroplasty and the use of patient specific guides and computerized planning, while interesting concepts, still await validation before they are utilized on a widespread basis. While reverse shoulder arthroplasty has been increasingly used to reconstruct the arthritic shoulder, anatomic glenohumeral replacement maintains a significant role in the armamentarium of the shoulder surgeon.

1. Evolution of humeral side prosthesis

The modern approach to shoulder arthroplasty was popularized by Neer in 1953 [1,2] with a stemmed humeral prosthesis for fractures of the proximal part of humerus. He later designed a glenoid component which improved the clinical results and the applications increased to include conditions not previously amenable to successful treatment with hemiarthroplasty alone such as rheumatoid arthritis [3].

While the most common method of failure in modern shoulder arthroplasty is on the glenoid side, Neer’s concept of a humeral component has withstood the test of time. He based the length of the humeral stem upon the concept of a 150 mm stem as was typically seen in total hip arthroplasty. Loosening of the traditional humeral component has been uncommon as a cause of failure of anatomical total shoulder arthroplasty (aTSA) in that there is a common observation that a “loose humeral stem is infected until proven otherwise” [4]. The Mayo Clinic experience with humeral stem loosening in 1584 shoulder arthroplasties was found to be “rarely a cause for revision” [5]. In their study, the survivorship of the humeral components was 95% at 5 years follow-up, 92% at 10 years, 87% at 15 years, and 83% at 20 years [5]. They also found that humeral loosening was commonly associated with glenoid component issues such as particulate disease from glenoid wear.

While the Neer humeral stem was fixed with cement similar to hip prosthesis of the day, there became a general trend in hip arthroplasty to press fit the femoral components without cement. This not only provided good results but also eliminated the tedious and difficult process of removing cemented femoral stems when necessary. Removal of a well cemented humeral component has also proven to be not only complicated but difficult, which is reflected in the high the complication rate when revising a cemented humeral stem [6]. Shorter operating times

* Corresponding author. Division of Shoulder and Elbow Surgery, Department of Orthopaedic Surgery, The Johns Hopkins University, 4194 Texas St., San Diego, CA 92104, USA.
E-mail address: webersc@earthlink.net (S.C. Weber).

https://doi.org/10.1016/j.jisako.2023.05.001
Received 27 January 2023; Received in revised form 30 April 2023; Accepted 11 May 2023
Available online 18 May 2023
2059-7754/© 2023 The Author(s). Published by Elsevier Inc. on behalf of International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
versus cemented stems and excellent mid-term survivorship has been shown with traditional length uncemented humeral stems [7], with this study citing a revision rate of uncemented press fit humeral stems as 1.4% at a mean of nine years.

Second generation anatomic TSA was described by Boileau and Walch et al. [8]. This group along with Pearl [9] were the first to recognize that the humeral head was not concentric like a circle but rather was asymmetrical as it relates to the long axis of the humeral shaft. While this change was made primarily by creating offset of the humeral head to cover the proximal humerus more anatomically, it has become a predominant feature of all subsequent aTSA systems. Boileau and Walch also advocated a variable inclination of the humeral head upon the shaft of the humerus. Ianotti et al. had noted that the humeral head's centre of rotation is offset from the humeral shaft medial 5 mm–11 mm and posterior 1 mm–5 mm. Humeral head inclination is variable at 40°–45° and the head height or thickness is 15 mm–20 mm from the anatomical neck axis [10]. Native version is an average of 18°–25° degrees retroverted, although this can range from 5° of anteversion to 60° of retroversion [10]. Lastly, in order to replicate proximal humeral anatomy, it became recognized that the humeral osteotomy should also reflect the retroversion of the humeral head on the humeral shaft. This is accomplished more easily in a proximal humerus with minimal bony deformity, such as in rheumatoid arthritis. However, distortion of the proximal humerus anatomy in severely arthritic shoulders presents some challenges in deciding what is the best retroversion to produce in the osteotomy. These design changes remain the benchmark in humeral stem design against which other designs can be measured.

2. Short stem humeral components—state of the art

The first shorter humeral stems were reported by Dr. Neer in 1982 [3]. He originally intended these monoblock implants to be used in patients with congenital dysplasia of the proximal humerus or in patients with proximal humeral deformity as seen in juvenile rheumatoid arthritis [3]. Despite this innovation, the use of short humeral stems was not re-introduced as an option until the 1990’s. The impetus for the use of shorter stems was to obviate damage done when extracting traditional long stem and cemented humeral components. Another touted advantage was that there would be fewer post-operative humeral fractures due to the absence of a diaphyseal stress riser with a shorter stem, and if there were peri-prosthetic fractures, they would be more amenable to or perhaps not require fixation. Fewer intraoperative fractures, faster surgery, and less blood loss were other purported advantages [11]. Lastly, shorter stem design was felt to allow for the reduction of stress shielding coming from smaller diaphyseal load due to a shorter stem [12,13].

There are, however, multiple potential issues with the use of short humeral stems. The first is the concern for stress shielding of the proximal humeral bone due to the density of the humeral implant. While the long term clinical consequences are unknown, stress shielding has not been avoided with shorter stems. The second was the risk of improper positioning of the implant. Without the diaphysis of the humerus as a guide for the shaft of the implant, the inclination of the head-neck junction could be affected if the stem is placed in too much varus or valgus. Lastly, if the bone was not of good quality, the possibility of subsidence leading to loosening of the implant became a concern. This concern remains, with these devices requiring careful assessment of the metaphyseal bone stock via mechanisms such as Churchills’ “thumb test” [14].

The first issue of stress shielding has not proven to be clinically significant in most studies with short- to mid-term follow-up. Nagels et al. [12] reported 64 patients with 70 humeral head replacements with traditional, long stem humeral prosthesis which had an average follow-up of 5.3 years. The incidence of stress shielding was seen in only 9% of patients, and there were no humeral shaft fractures or loosening of the implants. A study by Razafar et al. [15] found that proximal humeral stresses produced by short stem components closely matched the stresses seen in normal proximal bone without an implant. However, Giordano et al. actually showed more stress shielding with a short stem than a standard stem device [16]. Raiss et al. showed that only 49% of anatomic short stem and 65% of reverse short stem had no evidence for radiographic changes of stress shielding or loosening [17]. These authors noted that radiographic changes were increased in cases where high filling ratios of the device to humeral canal were noted. Erickson et al. in their systematic review noted a 22% incidence of calcar osteolysis, similar to that reported for traditional stems [18].

Precocious loosening has been a long-standing concern with shorter stems. Casagrande et al. [19] reported in a cohort of 73 shoulders who underwent a short stemmed humeral component at a loosening rate of 8.7% and radiolucent lines in 71%. However, Morwood et al. [20] reported 34 patients who were treated with the same short stem humeral device with proximal porous coating added. At a mean of 27 months, there were no revisions for loosening but 21% developed radiolucencies [20]. Other short-term studies appear to confirm these findings [22].

The second issue with short stem humeral components is accurate positioning of the prosthesis in the proximal metaphysis of the humerus [13,23]. While varus and valgus positioning of the implant seems innocuous, the tilt on the implant can affect the neck-shaft angle. This could have consequences with wear of the humeral head on the glenoid. Similarly, the implant can be placed in too much anterior or posterior tilt with similar results. Traditional length stems can avoid these problems.

Lastly, subsidence of the implants depends upon bone quality in the metaphyseal region of the humerus. Romeo et al. [24] reported upon 64 patients with a minimum follow-up of 2 years treated with a short stem humeral component. They described that 9% were at a risk for loosening but there were no clinical failures. Erickson et al. [22] reported the use of short stems for reverse TSA and found that the rates of tuberosity resorption, radiographic luencies, and component subsidence were lower in short stem components than standard length humeral components. In a systematic review, Erickson et al. noted only a 2% incidence of humeral loosening with shorter stems [18]. It is unknown if these published results will be duplicated by more general orthopaedists. As a result, the exact incidence of short stem humeral component subsidence is not known in the long-term, and careful assessment of the metaphyseal bone quality is recommended to avoid this complication.

3. Stemless implants—state of the art

The design of stemless proximal humeral components was introduced in England by Copeland in 1986 with resurfacing arthroplasty [25]. The humeral head was resurfaced with a metallic surface with a central peg and the glenoid with a cemented polyethylene component, although this device was most commonly used as a hemiarthroplasty. This design and subsequent designs of stemless implants are based upon the principle that the least amount of bone removed is the best approach to shoulder arthroplasty. The difference between resurfacing implants and stemless implants is that humeral head is not resected in the resurfacing implants. The continued presence of the humeral head can make glenoid exposure challenging in resurfacing devices. The first stemless implants were introduced in Europe in 2004: the total evolution shoulder system (Bio-press; Warsaw, Indiana) which gained widespread use [26]. There are now a number of stemless prostheses available, both in Europe and the US. Even with limited comparative data, the use of stemless arthroplasty is set to surpass standard stemmed arthroplasty in Europe by 2024 [27,28].

The clinical results of stemless implants are generally favourable at short-term follow-up [29]. There are several available systematic reviews of the studies which conclude that in the short run, there are few complications and promising radiological and clinical outcomes [27,30–35]. Registries have provided a similar assessment [36]. In their systematic review, Willems et al. [27] found no difference in Constant Scores or American Shoulder and Elbow Surgeons (ASES) scores between TSA with stemmed or stemless components. They also found that gains in the range of motion were similar for the two groups. Other comparative studies have provided similar outcomes in regard to clinical outcomes [35,37].
The indications for these types of implants are the same as for anatomic total shoulders in general and include good humeral bone quality in patients with an intact rotator cuff. These implants used as an aTSA should not be used in patients with poor proximal humeral bone, a torn rotator cuff, osteopenia or metabolic bone disease [26] and require careful intraoperative assessment of bone quality such as Churchill’s “thumb test” [14]. The use of stemless humeral components when there is significant metaphyseal deformity preventing the placement of a stemmed component remains an uncommon but valid indication [18]. Other touted advantages are similar to those touted for shorter stems include less blood loss and decreased surgical time [39], fewer proximal humerus fractures, preservation of proximal humeral bone, better clinical results due to more anatomic placement as the head position is not constrained by the humeral shaft [40] and ease of revision [11,41]. Review articles and comparative studies have failed to definitively confirm many of the purported advantages in primary stemless shoulder arthroplasty, with similar but not superior outcomes to standard stems [38]. Berth et al. in one of the few randomized controlled trials showed statistically significant decreases in operating time and blood loss with stemless implants, but the actual differences were of questionable clinical significance (100 ml average blood loss and 14 min of operating time) [39] Uscok et al. also did a randomized study showing no difference in functional outcome [42]. Huguet et al. actually showed a 7% rate of intraoperative fractures with a stemless device, 80% of which needed to be converted to a standard stem. Review articles have suggested reasonable long-term outcomes. In their systematic review, Willems et al. [17] found humeral component migration was seen in only 8 of 1184 cases (0.7%). There was an incidence of osteolysis in 0.9% of cases as well. There were a total of 93 reoperations in the stemless components (9.7%) of which 5.1% were revisions. Rotator cuff insufficiency was seen in 2.7% of the implants studied. Systemic review of 13 studies done by Erickson et al. shows a 2% humeral loosening rate in stemless implants, a 3% overall revision rate, and a 1% rate of revision for aseptic humeral loosening [20]. Huguet et al. showed similar results in their review [43]. While precocious loosening of stemless devices is largely not reflected in the literature, the 2017 UK recall of the Biomet Nano reverse stemless for abnormally high rates of precocious stem loosening and revision suggests that the failure to adequately assess bone quality at surgery with these devices is not trivial and perhaps underreported [21]. Although it seems intuitive, ease of revision for shorter stems than traditional stems remains challenging to establish as well. Tracy et al. presented one of the few comparative studies evaluating ease of revision for shorter stems. These authors retrospectively compared convertible humeral stems, short stems, stemless, and traditional stem humeral revisions at 10 different centres. Consistent with prior reports [44,45], only 70% of convertible stems could be retained. Another disadvantage of convertible stems is the risk of unrecognized infection at the time of revision. While complete revision of a prior stemless aTSA allows essentially a one stage revision for infection, late recognition after surgery of an infected platform system would most likely require additional surgery. Tracy et al. in addition noted that while stemless revision showed fewer intraoperative fractures than traditional stems (3.6%) but shorter stem and traditional stem revision had equivalent fracture risks (23.4% and 24%, respectively). Blood loss was less only for the shorter stem group, and as transfusion rates were low for all groups, the clinical significance of diminished blood loss was unclear. Operative times were on average 40 min shorter for stemless revision and 25 min shorter for shorter stem revision. Functional outcomes were not reported. Improved survivorship or functional outcomes revising failed aTSA from shorter stems has yet to be established. Holshen et al. had follow-up on 44 revisions of prior shoulder arthroplasty, 18 of which were stemless [46]. In their study, patients with stemless primary implants achieved a higher normalized constant score than patients with stemmed primary implants (82 vs. 61.8%; p = 0009), but the ASES scores, however, were not significantly different. The overall complication rate was not significantly different for stemmed (9.1%) and stemless (6.8%) primary implants. The removal of humeral components were difficult in 16.7% after stemless primary implants while difficulties occurred more often after stemmed primary implants (30.8%) [46]. One issue with stemless devices is that follow-up is still limited to mostly mid-term follow-up. Liu et al. noted that no studies had 10 year follow-up of stemless devices, and only 11 studies had mid-term follow-up [34]. One of the longest follow-up series was that of Hawi et al. with nine-year mean follow-up (range, 90–127 months) [47]. Magosch et al. extended the same series further, with mean period of follow-up of 126 months (range, 105–157 months) [48]. These authors noted no revisions for humeral loosening, but an 18.3% incidence of rotator cuff failure and a revision rate of 9.3% to reverse arthroplasty. Most studies regarding the clinical and radiological results of canal sparing stemless implants suggest that more studies with longer follow-up are necessary before their widespread use is recommended. The role of these implants in the treatment of shoulder conditions compared to traditional and short stems warrants further study as Piper et al. note that each has their advantages and disadvantages [49].

4. Glenohumeral arthroplasty surgical approaches—state of the art

The traditional surgical approach to shoulder arthroplasty remains the deltopectoral approach as described by Neer [3], but several alternative approaches have been suggested in an attempt to avoid instability, improve exposure, and limit damage to the rotator cuff [50]. Neer’s standard deltopectoral approach continues to show many advantages which include good visualization of the anatomy (especially of the inferior glenohumeral joint), ability to extend the approach as needed for access to the humeral shaft and glenoid, and utility in revision cases where extensive exposure is necessary.

Despite the ubiquitous use of the deltopectoral approach for shoulder arthroplasty, there are several variations described. McKenzie first described an anterosuperior approach for glenohumeral arthroplasty [51]. This approach was felt to provide superior exposure to the glenoid and rotator cuff. While this approach remains popular in some centres in Europe [11] especially for reverse replacement [52], difficulty with access to the inferior aspect of the glenohumeral joint has limited its widespread use.

One important detail in the exposure is the treatment of the subscapularis tendon as failure of the subscapularis tendon repair after aTSA is one of the most common modes of failure [53]. Failure of the subscapularis tendon can lead to uneven forces on the glenoid component and contributing to the “rocking horse” phenomenon [54]. Once the subscapularis tendon fails, the humeral component can also migrate superiorly which leads to superior subluxation of the humerus and subsequent loss of motion [55].

There are several ways to treat the subscapularis tendon as part of the standard deltopectoral approach [56]. The subscapularis tendon can be tenotomised leaving a stump on the lesser tuberosity to which the tendon can be attached later [57]. The subscapularis tendon can undergo a “slide:” where it can be released from the lesser tuberosity with the capsule and at the end of the procedure sewn back using transosseous sutures [56]. Lastly, the lesser tuberosity can be osteotomized with the tendon attached and sewn back to the proximal humerus with a variety of suture combinations [58]. Compromise of metaphyseal fixation of shorter stem and stemless devices with lesser tuberosity osteotomy has been raised as a concern [18,59]. Morwood [20] and others [59] in their reviews have shown reasonable outcomes with lesser tuberosity osteotomy with stemless designs, but clearly osteotomies involving a substantial part of the lesser tuberosity raise concerns for subsequent implant metaphyseal fixation. Studies have suggested that these different ways to treat the subscapularis tendon repair have similar clinical results [60–62], at least with traditional stem designs.

Other surgical approaches have been suggested to avoid the issues of rotator cuff failure after anatomical shoulder arthroplasty. Such
approaches basically avoid any detachment of the subscapularis tendon in order to prevent the consequences of later subscapularis tendon failure. These include exposures entirely through the rotator cuff interval [63], a “subscapularis sparing approach” [64,65], and a posterior shoulder approach [66,67].

The advantages of these approaches have been postulated to be improved pain, decreased subscapularis dysfunction or tearing, decreased rehabilitation time, and better access to some portions of the glenoid [67]. Amirthanayagam et al. [68] performed an anatomic feasibility between these three approaches and concluded that the posterior approach allowed greater access to the glenoid than the subscapularis splitting approaches and rotator cuff interval approaches. They found that the direct linear access to the glenoid was 59% of the glenoid circumference, 39% for the subscapularis splitting approach, and 37% for the rotator cuff interval technique [68]. The indications for these alternate approaches are patients with lesser degrees of arthritis and glenohumeral joint deformity [67].

These alternative approaches have not seemed to gain widespread use for TSA for several reasons. First, the type of TSA which was performed in several studies was limited to stemless designs. Greive et al. utilized a resurfacing humeral prosthesis in their study using the posterior approach [67]. Savoie et al. [69] performed subscapularis sparing approach where the humeral implant was a surface replacement in 48 patients and a stemmed humeral component in only 2 patients. This technique was not utilized for placement of the glenoid component in these cases.

Second, these approaches often release other structures beside the subscapularis tendon in order to gain exposure. The technique of Lafosse et al. [63] utilized a superior deltoid splitting approach but required a 4.5 cm subperiosteal release of the deltoid off of the acromion. Adkison et al. [64] reported a subscapularis sparing approach where 3–4 cm of the deltoid was released from the anterior acromion. Despite releasing and reattaching the deltoid, no reported cases of dehiscence were reported. Simovitch et al. [65] reported in their subscapularis technique the release of the coracoacromial ligament along with special modified instruments to gain exposure to the glenohumeral joint.

Lastly, at the current time, there is a paucity of literature with long-term follow-up using these various approaches designed to prevent subscapularis postoperative dysfunction and tearing. Follow-up with a minimum of 2 years includes 24 patients [66] with a posterior approach, 17 patients [63] with a superior rotator cuff interval approach, and 50 patients with a humeral head resurfacing with partial take down of the subscapularis tendon [69]. Further studies with longer-term results will be necessary before these approaches will gain more consideration for the implantation of anatomic shoulder arthroplasties. Regardless of the approach chosen, adequate capsular and subscapularis releases, complete osteophyte removal, and careful attention to anatomic variations are required. The surgeon’s skill in managing these releases and technical considerations is at least as important as the chosen approach.

5. Evolution of the glenoid side prostheses

Neer’s original glenoid component was a cemented, finned Ultra High Weight Polyethylene (UHWPE) component [3]. While resurfacing the glenoid stood to improve the results with previously published hemiarthroplasty, the cemented glenoid brought its own problems. As indications expand and procedure rates increase, focus has been turned to common modes of TSA failure to try and improve long-term survivorship and function. Glenoid component loosening remains a significant concern and the most common complication of shoulder arthroplasty [70,71]. Franklin et al. demonstrated early on that with rotator cuff deficiency that the forces transmitted across the glenoid are thought to cause component loosening secondary to combined rotational and translational moments moving the centre of the GH joint reaction force up to 11 mm from the anatomic centre of the glenoid throughout range of motion [72]. This eccentric loading of the glenoid implant is thought to impose a compression force across one end of the implant and a distraction force across the other thereby contributing to micromotion of the implant and subsequent eventual loosening [72,73]. Reverse replacement has resolved the issue of precarious glenoid loosening with arthroplasty in the setting of massive rotator cuff tears [74,75]. Similarly, many studies have suggested that reverse replacement may provide superior results in patients with profound glenoid deformity [76]. Anatomic total shoulder replacement still remains a viable option for many patients, however, with changes in the classic Neer component designed to improve outcomes.

6. Anatomic glenoid components—state of the art

A variety of advancements have been made surrounding the glenoid component to try and increase survivorship. In terms of material science, the all polyethylene component remains the gold standard secondary to unacceptably high rates of trabecular metal glenoid implant failure in the first ten years in some series (as low as 52% survival) [71]. A recent review of metal backed glenoids has shown improved results [77]. Highly cross-linked polyethylene has largely replaced standard UHWPUE due to superior wear characteristics [78]. All polyethylene cemented pegged and keeled components have shown similar survivorship [78]. All polyethylene glenoids with a central fluted peg have also shown excellent mid-term survivorship [79]. Although cleared by the U.S. Food and Drug Administration for cemented use only, the current practice has been to cement only the peripheral pegs, and the central peg is fixed cementless with autogenous bone graft [79]. While early results were encouraging, longer follow-up in a study by Ho et al. showed central peg lucencies to be associated with glenoid failure with these types of components [80]. In this study, twenty-one of 73 glenoids were clinical failures, with four going on to revision [80]. Recently, there has been some focus on hybrid glenoid fixation with an all polyethylene component with trabecular metal pegs [81]. Two year results compared to all polyethylene components have been promising but long-term survivorship is still unknown at this time [71]. Implant fracture and bead dissociation have also been reported [82]. Dillon et al. reviewed the survivorship of different types of glenoid components cemented pegged and keeled glenoids showed a significantly increased risk of revision than hybrid or all-polyethylene central peg designs at mid-range follow-up [78].

Additionally, some designers have advocated for inlay style prostheses where the glenoid component is recessed into the native glenoid [83]. Advocates cite biomechanical data demonstrating decreased edge loading of the implant in this configuration potentially decreasing the possibility of rocking horse phenomena loosening [83,84]. Short-term clinical outcomes have been promising clinically but long-term follow-up is still lacking [85,86]. Critics contend that the inlay component surrounded by native cartilage will over time function more like a hemic arthroplasty as native glenoid will come into contact with the humeral prosthesis during normal shoulder range of motion; therefore, long-term revision and complications rates are still needed [83].

Perhaps one of the biggest changes in shoulder arthroplasty with respect to the glenoid component has come with the advent of 3-dimensional (3-D) preoperative planning (Fig. 1). Proper implant positioning can improve outcomes and minimize the risk of early glenoid loosening [87]. In cases of bony deformity, achieving this proper placement can be even more difficult. Several series have demonstrated increased risks of impingement and early loosening when implants are positioned improperly [87–89].

Traditionally, plain radiographs and freehand central guide wire placement were utilized to position the glenoid component. However, with the growing popularity and ease of 3-D advanced imaging, these
techniques have been increasingly utilized, leading to better estimation of glenoid version and bony deformity [88]. In fact, a recent study demonstrated that from 2005 to 2014, the rate of patients (in a United States population) who had any advanced imaging for shoulder arthroplasty planning purposes increased over 400% [88]. Additionally, patients who underwent advanced 3-dimensional imaging demonstrated a significantly lower revision rate at two years in the same study [88]. This dramatic increase in available 3-D preoperative planning usage and tools has provided shoulder arthroplasty surgeons with the ability to critically assess glenoid component placement for version, size, perforation risk, and even evaluate the need for augmentation prior to surgery [71].

This technology has led to the advent of patient specific guides for glenoid central peg placement (Fig. 2). These guides can be created and manufactured for each patient based on surgeon selection off of notable patient specific glenoid morphology, or as Iannotti et al. demonstrated, a reusable adjustable guide can be configured off of a 3-D reconstruction of the patients glenoid for each case as well [87,90]. Overall these PSI approaches have increased precision of glenoid component placement compared to preoperative planning with 3-D models; however, it is unclear if this has translated to improved clinical results when compared to traditional methods with advanced imaging [87]. Similar results have been found when comparing computer-assisted surgical navigation systems with traditional standard instrumentation usage for placement of the glenoid component. Precise implant positioning can be achieved with minimal if any clinical difference being shown and no long-term follow-up describing a difference in survivorship [87,90]. Cost of this advanced technology also remains an issue. Schiffman et al. in their review noted that their review “did not identify evidence that the results of TSA were statistically or clinically improved over the 2 decades of study or that any of the individual technologies were associated with significant improvement in patient outcomes” [91]. Despite this, proof of concept literature exists working towards limiting cost, increasing feasibility, and decreasing excess surgical steps to make computer-assisted navigation more practical in the hopes that accuracy of implantation of the glenoid component translates to increased survivorship in the future [91,92].

In cases where significant posterior glenoid deformity is present, traditionally three options for treatment have been available eccentric reaming, posterior glenoid bone grafting, and augmentation. For retroversion cases less than 10–15°, eccentric reaming can show favourable results [93]. However, the downsides of eccentric reaming which include loss of bone stock, cancellous fixation, downsizing of the glenoid component, medialization of the joint line, and rotator cuff de-tensioning limit the generalizability of this approach [89,92]. Prior surgeons have also considered posterior bone grafting with allograft or autograft as a viable approach to correction of glenoid version; however, results have also been mixed secondary to technical difficulty and limited long-term follow-up secondary to nonunion, resorption, and collapse [94,95]. Finally, augmented glenoid components have gained some limited popularity as a means to correct significant posterior erosion without joint medialization [96]. Early short-term outcomes for augmented implants has been encouraging but again long-term survivorship results are limited and concerns for implant shear forces persist, as well as challenges associated with revising these implants [71, 97]. Ianotti et al. noted that while modest deformity was well managed with one type of augmented glenoid, more significant deformity appeared to be associated with radiographic signs of early failure [98]. Not all centres agree that retroversion need be corrected with any
Future perspectives

Ongoing development of the humeral components will keep focussing on current goals such as bone preservation with optimal component positioning, and the best range of motion avoiding impingement while supported by sufficient soft tissue tension. Cost consideration remains important and carefully calculated for different designs, with clear benefit for increased cost prior to widespread adoption. The traditional length humeral components have been in use for more than 40 years now with literature reports providing very reasonable long-term follow-up and outcomes. Short stem and stemless arthroplasties are still relatively new at least in terms of the available follow-up and long-term observations regarding potential problems. Surgical approaches will still remain the surgeons' preference with increasing data suggesting that approaches other than the traditional deltopectoral approach might be reasonable in individual cases. A personalized approach is needed for the best choice regarding not only the type of procedure but also the best design and surgical approach to implant the arthroplasty. On the glenoid side, the cemented, highly cross-linked, all polyethylene glenoid remains the standard of care. Modifications including hybrid glenoid components, newer metal backed components, augmented components, and 3-D imaging and computer-assisted surgery may all improve outcomes, but definitive data at this time is lacking. While the reverse arthroplasty is increasingly used to manage differing shoulder problems, the anatomic shoulder arthroplasty appears to retain a significant role in treating shoulder arthrosis.

Conflict of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Piotr Łukasiewicz reports a relationship with Medical Inventi that includes: consulting.

Stephen Weber reports a relationship with MSquared Associates and NDA Partners that includes: consulting or advisory services.

Edward McFarland reports a relationship with Stryker that includes consulting and speaker.


Box 1

Key articles regarding anatomic shoulder replacement


Contributors

All authors certify that they have participated sufficiently in the work to take public responsibility for the content. EGM and SW conceptualised and designed the work, participated in the acquisition and analysis of the data. All authors participated in interpretation of the data. JH, SS, TM, PL, EGM and MJM drafted the manuscript together with NN and CL and ECM who helped editing it critically for important intellectual content. All authors gave final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved

Box 1

- Dislocation: more frequent with stemless implants, less frequent with traditional stems.
- Hematoma: more frequent with short stems.
- Fractures: more frequent with stemless implants.
- Component loosening: more frequent with upside down heads.
- Component malrotation: more frequent with short stems.
- Component subsidence: more frequent with stemless implants.
- Component notching: more frequent with traditional stems.

Box 2

Validated outcome measures and classifications

Age adjusted Constant Score
American Shoulder and Elbow Score (ASES)
The Penn Shoulder Score (PSS)
Simple Shoulder Test (SST)
Disabilities of the Arm, Shoulder and Hand (DASH) score;
short version of the DASH questionnaire (QuickDASH)
Oxford Shoulder Score
Shoulder Pain and Disability Index

Box 3

Key issues of patient selection in anatomic shoulder arthroplasty

- Absolute contraindications include active infection, massive rotator cuff tear, and insufficient glenoid bone stock. Anatomic arthroplasty should be approached with caution in younger patients, especially those unwilling to moderate activities.
- Short stem and stemless implants require excellent metaphyseal bone stock to avoid later loosening and careful preoperative and intraoperative assessment is required to use these components.
- Regardless of the approach, meticulous handling of the subscapularis tendon is essential so that it remains attached and functional after surgery.
- Posterior glenoid bone loss is not uncommon in aTSA. This must be recognized and planned for preoperatively. Disagreement exists whether bone grafting, wedges, reverse replacement, or leaving in situ is the best technique of management.

Box 4

Essential and/or typical features of humeral and glenoid components in anatomic shoulder arthroplasty

- Humeral stems are currently modular, and provide for offset of the head from the shaft and variable neck-shaft angles.
- Stemless components are not constrained by the humeral shaft, and in theory allow more accurate reproduction of humeral anatomy than stemmed devices. In practice, however, the lack of constraint of the shaft can allow for malpositioning of the head, usually in varus.
- With rare exceptions of poor bone stock, most humeral components can be placed cementless with excellent mid and long-term outcome.
- Many of the purported advantages of shorter stem and stemless components in primary surgery, such as decreased blood loss, fewer fractures, and improved outcomes have not been established. Ease of revision and improved outcomes of revision compared to traditional stem devices remains to be definitively established as well. High-quality comparative studies evaluating differences in revision between traditional and shorter stem humeral components are lacking.
- Highly cross-linked all-polyethylene cemented glenoid components remain standard of care. Hybrid and metal backed glenoids may offer advantages but long-term follow-up is needed.
- Computer assisted surgical techniques offer theoretical advantages for more accurate component placement and improved survivorship, but it has been challenging to establish clear anatomic or clinical benefits.

Box 5

Tips and tricks in anatomic shoulder replacement

- Careful patient selection is necessary to avoid complications and early failure of aTSA. Younger patients especially should be counselled that activity modification will be necessary, and that failure requiring revision is possible during their lifetime.
- Pre and intraoperative assessment of the state of the rotator cuff is essential. Given that rotator cuff failure is one of the major causes of late revision, thought should be given to primary reverse replacement if there are any questions.
- Regardless of the management technique chosen, meticulous attention to the management of the subscapularis is required.

Box 6

Major pitfalls in anatomic shoulder replacement

- Humeral loosening with aTSA is rare with traditional length stems. Short stem and stemless humeral components however require adequate bone stock to support these implants. Intraoperative assessment that bone stock is inadequate requires conversion to a standard length implant. A loose humeral stem should be presumed to be infected until proven otherwise.
- Lesser tuberosity osteotomy should be used with caution on short stem and stemless implants.
- Regardless of the technique chosen to manage glenoid deformity, adequate glenoid exposure and complete seating of the component against the native bone is required to avoid early glenoid component loosening, the principle cause of late revision in aTSA.


