Outcomes and survivorship of anatomic total shoulder arthroplasty: current concepts

Kristine Italiaa,*, Mohammad Jomaa,b,c, Roberto Pareyona,b,c, Freek Hollmana,b,c, Kenneth Cutbusha,c, Ashish Guptaa,b

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ABSTRACT
Total shoulder arthroplasty (TSA) has been the gold standard of care for end-stage glenohumeral arthritis. Outcomes are varied and have been affected by both patient and implant characteristics. Patient factors, such as age, preoperative diagnosis, and preoperative glenoid morphology, can affect the outcomes after TSA. Similarly, the different glenoid and humeral component designs significantly affect the survivorship of TSA. Significant evolution has occurred in the design of the glenoid component with the aim of decreasing the glenoid-sided causes of failure in TSA. On the other hand, focus on the humeral component has been increasing as well, with a trend towards using shorter humeral stems. This article aims to look at the outcomes of TSA as affected by the various patient characteristics and design options for the glenoid and the humeral components. This review also aims to compare survivorship data from global literature and the Australian joint replacement registry and to provide insights into the implant combination that may provide the best patient outcome.

Current concepts
• Anatomic total shoulder arthroplasty (TSA) has satisfactory outcomes for glenohumeral arthritis with intact rotator cuff tendons.
• Glenoid component loosening is one of the leading causes of failure and revision in TSA.
• Several factors contribute to the survivorship of TSA, including patient's age, preoperative glenoid morphology, diagnosis, glenoid design and humeral component design.

Future perspectives
• The use of augmented glenoid components has been described as one of the techniques to correct eccentric glenoid deformities and address glenoid bone loss. Long-term prospective studies with higher quality evidence are needed to determine the superiority of this technique over reverse shoulder arthroplasty.
• Shorter humeral stems are showing promising results. There is an increased use of stemless designs for total shoulder arthroplasty, and their long-term outcomes need to be compared with that of the standard stems in the coming years.

Abbreviations: TSA, Total shoulder arthroplasty; RSA, Reverse shoulder arthroplasty; OA, Osteoarthritis; MBG, Metal-backed glenoid; XLPE, Cross-linked polyethylene.
* Corresponding author. Suite 306 Nicholson St Specialist Centre, Level 9, 121 Newdegate St. Queensland, 4120, Australia. Tel.: +61 732085552.
E-mail addresses: kristine_italia@yahoo.com, kritalia@stlukes.com.ph (K. Italia).

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1. Introduction

Glenohumeral arthritis is a debilitating condition causing pain and dysfunction that can affect activities of daily living. Total shoulder arthroplasty (TSA) is the treatment of choice for end-stage shoulder arthritis. However, this is also associated with complications such as loosening, instability, rotator cuff insufficiency, and infection [1,2]. This article aims to discuss anatomic TSA outcomes as affected by different variables. Key factors affecting survivorship are emphasized, including patient factors and prosthesis characteristics.

2. Patient characteristics

2.1. Age

The survivorship of TSA for osteoarthritis (OA) is generally poorer in younger patients [1]. The Australian Registry reported that at 10 years, the highest cumulative percent revision is noted in 55–64 years old (16.2%), whereas lowest in patients 75 years and older (7.7%) [1]. The higher revision rate in younger patients can be attributed to longer life expectancy coupled with increased demand in the presence of more severe disease [3,4]. This places more mechanical stress on the rotator cuff and the implants causing increased wear, resulting in earlier implant loosening and revision [3,5].

Literature on the higher revision rates in young patients is ubiquitous. Dillon et al. [6] reported that patients 59 years and younger have double the risk of revision compared with patients older than 59. Denard et al. [7] showed radiologic glenoid loosening in 43.8% of TSA procedures in patients <56 at 9.6 years, with only 62.5% survival rate at 10 years. Even with all-polyethylene cemented glenoid components, one in four prostheses would fail at 12 years in patients <60 years [8]. A cut-off age for TSA of 65 has been suggested, as patients younger than 65 are at higher risk of revision (6.9% vs. 2.1% in >65 years) and tend to do worse in terms of range of motion (ROM) and function at final follow-up [3].

These unsatisfactory results have led some authors to consider TSA relatively contraindicated in young patients with higher physical demands [9]. Other authors advise their young patients not to participate in high-impact sports postoperatively [10]. Nonetheless, Garcia et al. [11] have shown that TSA can still lead to high satisfaction and return to sports in patients <55 years. No revision surgeries were related to glenoid loosening during the mean follow-up of 61 months [11].

Concerns are also raised regarding the use of TSA in the elderly due to a higher chance of having age-related rotator cuff dysfunction [12]. Even with intact cuff, some have recommended RSA in patients 70 years and older because of the possibility of secondary cuff failure after TSA [2]. Jensen et al. [2] investigated the outcomes of TSA in patients 70 years and older with primary OA with shoulders having some degree of glenoid bone loss and some degree of posterior or anterior humeral head subluxation. They have shown a low revision rate (0.8%), low incidence of secondary rotator cuff tears (1.3%), no radiographic evidence of humeral component loosening, and some evidence of glenoid component loosening (2%) but no instances of complete implant failure [2]. However, they noted progression of anterior and superior humeral head subluxation, which may indicate rotator cuff thinning or dysfunction over time, though this did not correlate clinically [2]. When compared with RSA, Wright et al. [13] noted no significant difference in complication rates (13.7% for TSA vs. 12.1% for RSA) and revision rates (6.9% for TSA vs. 3% for RSA) in 70 years and older diagnosed with OA and with no full-thickness rotator cuff tears, though the reasons for revision were different [13]. Pain scores and patient-reported outcomes were also similar between the two groups, with a high satisfaction rate for both [13]. Iriberri et al. [14] investigated the outcomes of TSA in a much higher age group of 80 years and older and suggested that excellent results can still be expected in this age group when the rotator cuff is intact preoperatively. Clinical and radiological outcomes were similar to those of patients younger than 70, with 3% secondary rotator cuff tear (vs. 6.3%), 18% radiological glenoid loosening (vs. 18%), and 6% radiolucent lines around the stem (vs. 9.3%) [14].

2.2. Glenoid morphology

Among the different types of glenoid morphology, B2 glenoids are the most challenging because of the associated retroversion and humeral head subluxation. It has been shown that a retroversion of 27° or higher has a 44% risk of complication, and a humeral head subluxation of 80% or more has an 11% risk of dislocation [15]. Hussey et al. [16] have also shown that patients with eccentric glenoid erosion had a 2-fold increase in radiographic evidence of gross glenoid component loosening compared to those with concentric wear (12.2% vs. 5.6%) after over 4 years from TSA. Hence, B2 glenoids have been associated with poorer implant survivorship because of the increased risk of recurrent instability and early glenoid loosening, especially if the version is not corrected [15].

Recently, the Australian Registry has shown that glenoid morphology is not a risk factor for revision in TSA [1]. The cumulative percent revision rates associated with the different glenoid types were 5.4% for A1, 5.3% for A2, 4.3% for B1, 4.6% for B2 at 4 years postoperatively [1]. This is similar to other studies showing no association between preoperative glenoid wear or humeral head decelerating and outcomes [17,18]. Another study comparing TSA in A1 and B2 showed no significant difference in glenoid radiolucent lines, revision rates (3% for A1, 5% for B2), and complication rates (5% in A1, 7% in B2) when eccentric reaming is performed for B2 glenoids [19]. A recent meta-analysis has also shown comparable radiologic and clinical outcomes between RSA and TSA with eccentric reaming or posteriorly augmented glenoid component for B2 glenoids (pooled revision rate of 2% for TSA, 1% for RSA) [20]. They noted higher average active abduction and external rotation in patients after TSA than RSA (142° vs 129° for flexion, 47° vs 32° for external rotation, respectively) and almost similar mean flexion at final follow-up (149° vs 151°, respectively). Hussey et al. similarly reported satisfactory improvements in pain, ROM, and function after TSA in patients with eccentric glenoids [16].

These favourable results in recent studies may be associated with better patient selection, improved surgical techniques, and implants to effectively correct preoperative glenoid deformity and humeral head deceleration [17,18]. These studies have shown that correcting the retroversion and humeral head subluxation is key to satisfactory outcomes. Augmented glenoids have shown promising results (Fig. 1), whereas caution is advised with posterior bone grafting for version correction as this has been associated with high rates of glenoid component loosening, graft resorption, non-union, graft collapse, and posterior dislocation [20].

2.3. Preoperative diagnosis

TSA has been reliably used for glenohumeral OA with intact rotator cuff. The satisfactory outcomes throughout the years have proven its reliability for this indication [1,17]. The indications for anatomic TSA have expanded to include other pathologies, like proximal humerus fracture, old trauma, cuff tear arthropathy (CTA), prior recurrent dislocation, avascular necrosis, and tumour [1,21]. There is a lack of literature comparing the outcomes of TSA for the different preoperative indications. Based on the Australian Registry, the highest cumulative percent revision at 7 years is seen in TSAs performed for CTA (16%) and fracture (15.8%), and lowest for rheumatoid arthritis (RA) (5.6%), followed by OA (8.4%); however, the differences were not statistically significant [1]. When analysing literature on the outcomes of TSA on each diagnosis separately, it generally shows that TSAs performed for glenohumeral arthropathies with aetiology that affect the rotator cuff (e.g. dislocation arthropathy [22–24], fracture sequelae [25,26], CTA [1]) do not do as well as those performed for arthritis with intact rotator cuff.
3. Prosthesis characteristics

3.1. Glenoid component

Cuff failure and glenoid component loosening are some of the leading causes of revision of TSA [1,27]. The mechanism of glenoid loosening due to soft tissue imbalance is known as the “rocking horse” phenomenon, but the means of failure is thought to be influenced by its design as well [27]. Multiple generations of implant designs have been introduced on the market in an attempt to optimize fixation and improve survivorship.

3.1.1. Glenoid component design: all-polyethylene, metal-backed, modularity

To improve the fixation of all-polyethylene glenoid components and reduce radiolucency, polyethylene components with metal backing were developed [28,29]. Earlier metal-backed glenoid (MBG) designs incorporated a metal platform that was secured to the glenoid with screws and were modular. This often resulted in an implant thicker than the all-polyethylene components, which may lateralize the joint line. This can result in overstuffing of the joint, which subsequently alters the mechanics of the rotator cuff. The lateralization increases the joint reactive forces that contribute to edge loading of the glenoid component, leading to polyethylene wear or premature loosening [30]. These modular implants were reported to have high rates of screw breakage, excessive polyethylene wear, dissociation, and high revision rates [31]. This is similar to the Australian Registry, which reports the highest revision rate of 26% at 14 years for modular implants, with several implants removed from the market or marked as an implant with a higher than anticipated revision rate [1]. Boileau et al. [32] investigated the modular implant's survival in primary OA and concluded that due to high revision rates, uncemented MBG resurfacing is not a viable long-term therapeutic option because of accelerated polyethylene wear leading to early revision surgery.

The initial non-modular MBG reported a failure rate of 21% due to fracture at the glenoid peg–baseplate junction [33]. Biomechanical testing showed that the amount of anteroposterior humeral head translation was underestimated and caused significant failure. Its design was changed and re-introduced in 2009 as the second-generation monoblock trabecular metal-backed hybrid implant. These implants show promising survivorship with long-term stability through bony ingrowth, as shown in several studies on non-modular (hybrid) implants [34,35]. This is in line with the Australian Registry reporting a cumulative percent revision of 8.2% at 10 years, which is much lower than that of the modular MBG (20.7%) and close to that of the all-polyethylene glenoids (6.7%) [1].

3.1.2. Glenoid component shape: keeled versus pegged all-polyethylene

After the initial keeled design, the pegged design was introduced to reduce the resection of subchondral bone and to utilize stronger peripheral bone for fixation [29]. Results from the Australian Registry have shown no significant difference in the revision rates between the two types at 7 years (5% for pegged, 4% for keeled) [1]. This is similar to several recent studies showing no difference in the rates of loosening and revision between the keeled and pegged designs [36,37]. This has been attributed to modern and improved surgical techniques [36].

3.1.3. Glenoid component polyethylene: non-cross-linked polyethylene versus cross-linked polyethylene

Based on biomechanical and clinical data, supportive literature favours using cross-linked polyethylene (XLPE) over non-XLPE [38,39]. Non-XLPE has a higher osteolytic potential which is reflected by the results from the Australian Registry reporting a significantly lower cumulative percent revision for XLPE at 10 years (4.4% vs. 12.7% for non-XLPE) for all glenoid types [1]. This may be attributed to less wear and particle generation, decreasing the risk of osteolysis, and subsequent loosening and failure [39].

3.1.4. Fixation technique: cementless versus cemented versus hybrid

Comparative literature on the fixation technique of the glenoid component mainly relies on registry data from Australia and New Zealand. Based on the Australian Registry, cementless glenoid components have the highest revision rate at 14 years (23.2%), whereas hybrid fixation with cemented glenoid components has the lowest failure rate at 14 years (8.7%) [1]. This is similar to the results of the New Zealand Joint Registry, which showed five times higher revision rate for cementless glenoid components [40].

3.2. Humeral component

One of the main objectives of TSA is to restore the overall geometry of the proximal humerus. The design and fixation of the humeral component have evolved over the last 20 years to allow anatomic restoration of premorbid proximal humerus anatomy or adapt the implants to the condition of soft tissue [41].

3.2.1. Humeral head size

Anatomic humeral head arthroplasty aims to restore anatomic relationships, specifically the centre of rotation of the articular surface. The resected head provides an excellent reference for selecting the correct diameter and thickness [41]. However, because the articular surface is generally deformed from the arthritic changes, it is often difficult to accurately measure the size of the premorbid humeral head resulting in the necessity to adjust to soft tissue balancing [42]. The Australian Registry has shown that TSA survivorship improves with increasing head size, with >50 mm having the lowest cumulative percent revision at 10 years (8.8%) and <44 mm having the highest (13.6%) [1].
Despite these results, it does not necessarily mean that bigger head size is always better. Increasing the humeral head thickness more than the native humeral head can result in overstuffing of the joint and over-tensioning of soft tissues causing significant decrease in ROM [42,43]. On the other hand, decreasing size can lead to greater tuberosity impingement and point loading on the glenoid [41,43]. It is recommended that thicker head may be required in arthritic shoulders with severe posterior subluxation to achieve proper tension of the posterior capsule and cuff. On the other hand, downsizing may be needed in avascular necrosis to avoid stiffness [41].

Based on the Australian Registry, the cause of early failure across all head sizes is rotator cuff insufficiency followed by instability [1]. In the second year after TSA, rotator cuff insufficiency becomes the main reason for revision for heads 50 mm or smaller [1]. Loosening is more apparent in heads >50 mm, with increasing incidence starting at year 8 post-operatively and becoming the main reason for revision at 12 years [1].

### 3.2.2. Humeral stem

The stem is one factor affecting TSA survivorship, as this is responsible for the load transfer to bone [44]. In shoulder arthroplasty, the stresses in the humerus are altered as load is borne initially by the implant and then transferred to the central trabecular bone before diffusing into the cortical bone more distally [44]. Hence, stress shielding in the proximal humerus can occur with longer stems [44].

There has been a recent trend in using shorter or stemless humeral components to lessen the risk of complications associated with longer stems, such as stress shielding and subsequent stem loosening (Fig. 2). The advantages of stemless implants include decreased surgical time, less blood loss, low risk of stress shielding, recreation of centre of rotation independent of the shaft axis, preservation of bone stock, and lower risk of diaphyseal stress risers [45,46]. Existing studies are promising, with satisfactory clinical outcomes and revision rates between 7% and 14% [47,48].

In one of the biggest meta-analyses on this topic, Willems et al. [49] reviewed 31 studies involving 1944 stemless implants and reported good functional results in mid-term follow-up. Radiologic outcomes are also better than stemmed implants, although a correlation with improved clinical outcomes in the long-term is needed [49]. On the other hand, a study by Martens et al. compared the long-term survival rates of stemless shoulder prosthesis with stemmed anatomical TSA [50]. They reported that the ten-year unadjusted cumulative survival rate of the stemless prosthesis (91.5%) was comparable to that of the stemmed humeral component (95.3%, p = 0.251).

These potential advantages make stemless implants very attractive. However, long-term and well-designed studies are needed to assess the superiority of stemless over stemmed designs, especially for revision surgeries [49].

### 4. Conclusion

TSA is a reliable treatment for glenohumeral arthritis with intact rotator cuff. This article presented a variety of patient and implant factors that affect the outcomes after TSA. Good patient selection and proper indication are necessary. Patient factors that may negatively influence outcomes include younger age, eccentric glenoid deformity, and etiology of arthritis that generally affects the rotator cuff tendons.

Moreover, a clear understanding of the patient's pathology is needed to select the appropriate implants that best address the pathology with the least risk of failure. Cemented, XLPE all-polyethylene glenoids show the best results, whereas MBG components show poor survivorship. Augmented glenoids to address glenoid deformities and hybrid fixation show promising results. For the humeral component, TSA survivorship improves with increasing head size, whereas shorter humeral stems are showing favourable outcomes.

### Declaration of competing interest

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