Current Trends in Shoulder Replacement: The Rational for Inlay Arthroplasty

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Abstract

Introduction: Shoulder arthroplasty utilization worldwide has undergone significant changes in the past two decades. Early on, the procedure volume was relatively small and demonstrated a preference towards hemiarthroplasty. Starting with the new millennium, the overall arthroplasty volume not only drastically increased, but also showed a tendency towards younger patients. Recent reports revealed that more than three quarters of all shoulder arthroplasty procedures are performed as a stemmed total or reverse procedure. Younger patients result in a clear increase in the revision rate across all conventional implant classes as evidenced by arthroplasty registry results. Increased modularity and adaptability of modern stemmed arthroplasty improved the procedure, but remains largely non-anatomic with continued use of spherical humeral head and onlay glenoid components.

The purpose of this review is to highlight the technical and clinical advantages of inlay shoulder arthroplasty and to differentiate it from onlay resurfacing procedures and the current trends in shoulder arthroplasty. Resurfacing arthroplasty is an implant class consists of onlay hemi and total resurfacing, partial inlay and total resurfacing. The distinction is important as onlay procedures use spherical humeral head and onlay glenoid components whereas inlay arthroplasty is taking the geometrical humeral head mismatch into consideration and avoids glenoid related joint line changes. In keeping the glenohumeral joint volume near the native conditions, biomechanical and kinematic advantages can be appreciated. Registry results showed the lowest 5 year cumulative revision rate for partial inlay arthroplasty across the treatment spectrum and clinical results from stemless total resurfacing using non-spherical humeral head and inlay glenoid components display great promise for a new path in primary shoulder arthroplasty.

Introduction:

Shoulder arthroplasty as a specialty has undergone significant changes in the new millennium (11,19,24,39,44). This did not only cause a marked increase in procedure volume, but also a shift in the use of specific implant classes and age related trends towards younger patients (2,37,43). Combined, these factors have led to a substantial increase in revisions (44) and may have a significant impact on the long term management of shoulder patients. In the context of these developments, contemporary primary shoulder arthroplasty continues to show a disregard for joint preservation and anatomic surface reconstruction with preferential use of stemmed total and reverse procedures (11,35,43,44). Modularity and adaptability are important aspects of modern stemmed procedures (4,16,48); however, with continued use of spherical humeral head and onlay glenoid components, these procedures remain largely non-anatomic. The purpose of this review is to summarize trends in shoulder arthroplasty and present a rational for inlay arthroplasty as a less invasive alternative in primary shoulder replacement.

Morphology and Biomechanics of the Humeral Head

Since the introduction of modern shoulder arthroplasty by Neer (36), evidence on the non-spherical nature of the humeral head (HH) has steadily increased for more than 50 years with reports on biomechanical and morphological data that reference the native shape of the humeral head.

In 1955, Neer (36) described the superior edge of the humeral head as somewhat flattened. In 1979, Clarke (8) showed that the best match to the plane of the cross sectioned humerus was in form of an elliptical shape. This was reconfirmed by multiple studies over the following three decades (1,3,6,18,20,21,31,42,49,50). Other studies comparing the major and minor planes of the HH reported a dimensional mismatch with a range from 1.6 to 6.5 mm (8,18,20,21,22,42,49).

The principal goal for primary shoulder arthroplasty is to restore normal glenohumeral joint kinematics (23). Jun et al. (22) compared custom non-spherical and commercially available spherical implants to the native humeral head and...
showed that the non-spherical shape fit the native HH better. The study reported a significant reduction in rotational range of motion for spherical heads (mean 7.6 +/- 8.2 degrees) compared to the native humeral head; no statistical difference in rotational range of motion was found between the non-spherical and native conditions. The authors concluded that the use of non-spherical heads may improve functional results after shoulder arthroplasty by more closely approximating the rotational range of motion and kinematics of the native humeral head as compared to the current spherical prosthetic designs. The kinematical advantages of non-spherical implants were reconfirmed by the authors in their most recent publication: The non-spherical humeral head shape contributed to increased glenohumeral translation whereas the aspherical head shape did not show significant glenohumeral translation during humeral axial rotation, regardless of glenoid conformity (23).

### Trends in Shoulder Arthroplasty Procedure Volume

In 1993, the US shoulder arthroplasty volume included 13837 procedures with a slight preference for hemiarthroplasty (54%) over total shoulder arthroplasty (46%). In 1999, the total volume had increased to 19113 procedures and the preference for hemiarthroplasty remained (56%) (24). Since the start of the new millennium, shoulder arthroplasty experienced a drastic rise. The American Academy of Orthopaedic surgeons (AAOS) reported an absolute increase in primary procedures from 18,621 discharges in the year 2000 to 45,274 discharges in 2011 (2) with other estimates reporting a total of 66,485 for the same year (43). The Australian orthopaedic association's annual shoulder arthroplasty registry report mirrored this trend. Since 2004, the registry recorded 32,406 shoulder replacement procedures (35). Starting in 2008, the number of shoulder replacement procedures has increased by 88.5%. Dillon et al. published their results on 6,336 primary shoulder arthroplasties recorded from 2005 - 2013 in the Kaiser Permanente shoulder arthroplasty registry (11). Procedures were classified as a total shoulder arthroplasty in 48%, followed by hemiarthroplasty procedures in 34%, reverse total shoulder arthroplasty in15%, and humeral head resurfacing in 3%. Shoulder arthroplasty utilization was based on the following diagnoses: Osteoarthritis (60%), fracture (17%), cuff tear arthropathy (15%), and avascular necrosis (2.6%). The all cause revision rate for elective shoulder arthroplasty was 4%. The most common reason for revision was glenoid wear following hemiarthroplasty or onlay humeral head resurfacing (27% of all revisions) followed by deep infection (20%), instability (18%), rotator cuff tear (17%), and glenoid component failure. Patients less than 60 years of age receiving a hemiarthroplasty had an almost 5 times higher revision risk than those patients who received a TSA.

### Procedure Type

Based on current Australian utilization, primary total shoulder replacement is the most common category (71.8%), followed by primary partial (17.9%) and revision procedures (10.3%). The proportion of total shoulder replacement has increased from 57.5% in 2008 to 82.1% in 2015. The majority of this increase has been led by a more than a fourfold increase in reverse total shoulder arthroplasty over this time frame. Between 2008 and 2015, partial shoulder replacement decreased from 32.6% to 7.2% (35). A similar trend towards total shoulder replacement has been reported in the US. Schwartz et al. showed a fivefold increase in primary total shoulder utilization based on a national hospital discharge survey with data from 2001 to 2010 (44). Based on 2011 estimates published by Schairer et al. (43), 32.6% of all procedures were reverse shoulder arthroplasties (RSA), 44.2% were total shoulder replacements, and 23.2% were hemi arthroplasty procedures.

### Revision Rates by Age

Shoulder implant classes demonstrate an overall trend towards higher revision rates with younger patient age. The 5 year cumulative percent revision for primary hemo onlay resurfacing in patients under 55 years was 10.4, compared to 8.1 in the 55-74 year old patients and 6.6 in patients over 75 years. Similar 5 year trends were reported for primary stemmed hemiarthroplasty with a revision rate of 13.1 (<55 years) versus 7.0 (>75 years) and 11.0 (<55 years) versus 6.7 (>75 years) for primary stemmed TSA (35).

### Hemi versus Total Shoulder Replacement

Several comparative studies support the preference towards TSA. A systematic review and meta-analysis conducted by Bryant et al. (5) compared TSA to hemiarthroplasty (HA) at a minimum of 2 years follow up. A total of 112 patients (62 TSA, 50 HA) were included in the review. The authors concluded that TSA showed better functional improvement than HA and contributed continuous degeneration of the glenoid to the result. In a 10-year update, Sandow et al. showed that 42 percent of the surviving TSA patients rated their shoulders as pain free while none of the HA patients were free of pain at 10 years (41).

Radney et al. (40) conducted a systematic review comparing TSA to humeral head replacement (HHR) and concluded that TSA significantly improved pain relief, range of motion and patient satisfaction. TSA also had a significantly lower revision rate (6.5%) compared to patients undergoing HHR (10.2%).

Garcia et al. (13) reported on patients with osteoarthritis (OA) who wished to return to sports following a total or hemi shoulder arthroplasty. He found that the rate of
for intraoperative measurements and however, IA preserves anatomic landmarks head morphology into consideration; procedures, nor onlay resurfacing the native geometry. Neither stemmed IA uses anatomic references to reconstruct previously (17,46,47). The surgical screw and articular component are connected via morse taper. The surgical reamers prepare an implant bed, and the screw and articular component are connected via morse taper. The surgical procedure has been described in detail previously (17,46,47).

Inlay Arthroplasty
Shoulder resurfacing as a less invasive alternative to stemmed arthroplasty has been popularized by Copeland and Levy (27-29,34). Despite the inherent advantages from a joint preservation perspective, the use of spherical onlay implants has not been void of criticism. Five year revision rates for hemi onlay resurfacing (10.6%) have been higher than their stemmed counterparts (8.5%) (35). Despite previous reports of overstuffing or varus placement (32,45), underlying reasons are not yet fully understood.

Inlay arthroplasty (IA) represents a departure from the use of spherical humeral head configurations. The concept was introduced more than decade ago and started with partial humeral head surface reconstruction, which was expanded in recent years to full head coverage. The system consists of various humeral head diameters ranging from 25 to 88mm. Each diameter has an array of shapes that allows for congruent surface reconstruction within the curvature of the humeral head. The two piece implant consists of a screw that is placed into the center of the defect for the purpose of fixation and surface measurement and an articular component that matches the superior-inferior (SI) and anterior-posterior (AP) curvatures of the surrounding surface. The contour is mapped intraoperatively, corresponding surface reamers prepare an implant bed, and the screw and articular component are connected via morse taper. The surgical procedure has been described in detail previously (17,46,47).

IA uses anatomic references to reconstruct the native geometry. Neither stemmed procedures, nor onlay resurfacing procedures take the non-spherical humeral head morphology into consideration; however, IA preserves anatomic landmarks for intraoperative measurements and reconstruction thereby keeping soft tissue tension and the moment arms of the shoulder muscles intact. Technical challenges associated with stemmed procedures are avoided by maintaining humeral head height, version, offset, and joint volume. This may not only have positive implications for postoperative recovery and rehabilitation, but also reduces the risk of implant related pressure on the rotator cuff and subscapularis repair following the customary deltopectoral approach.

Hemi and total onlay resurfacing procedures using spherical implants reference the implant diameters off the larger superior-inferior humeral head plane to gain complete surface coverage. The non-physiological joint volume increase in the anterior-posterior plane can be avoided by using non-spherical implants that respect the SI – AP mismatch.

Similar to onlay total shoulder resurfacing, IA allows for total resurfacing of the glenoid vault using dedicated 30 degree off axis reamers. Following preparation of the humeral head, the glenoid vault is accessed from the front using a circular paddle reamer. Single or double circle inlay glenoid components allow for surface reconstruction without lateralizing the joint line. Keeping glenohumeral volume contributions at their native levels may have positive implications for postoperative pain relief and functional improvements.

Biomechanical Comparison
The concept of inlay glenoid resurfacing has been previously described by Gunther et al. (15). Following cyclic loading to 100,000 cycles, no inlay glenoid components demonstrated signs of loosening. Finite element analysis results indicated that the inset technique achieved up to an 87% reduction in displacement compared with the onlay pegged implant and a 73% reduction compared with the onlay keel implant. Onlay implants exhibited high stress at the implant edges in form of a rocking-horse stress distribution, whereas the inset design did not show the rocking-horse stress distribution. The authors concluded that cyclic loading and finite element analysis support the concept of inset glenoid fixation in minimizing the risk of glenoid loosening.

Recently, Gagliano et al. (12) presented their results comparing onlay versus inlay glenoid prosthetic design survivorship characteristics in total shoulder arthroplasty at the 2015 Orthopaedic Research Society Meeting (ORS). The study showed visible loosening in all onlay implants in less than 2000 cycles, whereas none of the inlay components showed signs of loosening following 4000 cycles.

A biomechanical study by Hammond et al. (17) reported on the comparison of the intact glenohumeral joint to that following HH inlay arthroplasty and stemmed hemiarthroplasty. IA restored the center of rotation more closely than stemmed hemiarthroplasty and the glenoid had demonstrated less eccentric loading. The authors concluded that IA may provide better functional outcomes for patients as the biomechanics of the joint and the moment arms of the rotator cuff and deltoid more closely resembled the intact condition.

Clinical Results
The Australian Shoulder Arthroplasty Registry has been reporting on inlay arthroplasty since 2010. While the procedure volume has remained low, the revision rate (RR) has shown dramatic differences comparing partial inlay arthroplasty to other implant classes. In the 2016 report (35), the 5 year cumulative RR of partial inlay arthroplasty was 1.5%. No other implant class showed comparable registry results. As an implant class, hemi onlay resurfacing at 5 years had a cumulative revision rate of 10.6%, which was highest with Global CAP implants (12.8%, primary diagnosis OA), followed by Copeland (9.1%, primary diagnosis OA), and Aequalis (9.0%, primary diagnosis OA). These results highlight the importance of differentiating among inlay and onlay surface reconstruction methods. When addressing the glenoid as well, the 5 year cumulative revision rate of total onlay resurfacing was lowered to 7.3%. For comparison, the 5 year RR for stemmed hemiarthroplasty was 8.5%, for stemmed...
total shoulder arthroplasty 8.1%, and for
total reverse arthroplasty 4.6%. It remains
important to view registry and literature
reports in the context of patient age and
clinical exit opportunities. Procedures that
are amenable for younger patients will be
subject to higher demands and increased RR
as reported earlier. End stage procedures
such as stemmed total shoulder replacement
and reverse arthroplasty face increasing
technical demands when revision
procedures become necessary. The
management of patient expectation is
generally more restrictive in these
arthroplasty solutions when compared to
less invasive alternatives and may impact the
patients' desire to undergo further surgery.
Therefore, end stage procedures may show a
false positive revision rate due to the lack of
treatment alternatives.

Advanced stages of osteonecrosis of the
Humeral Head (ONHH) with separation of the
subchondral bone or contour collapse
are typically managed with arthroplasty.
Uribe et al. reported on the use of partial
inlay arthroplasty for advanced stage
ONHH (47). The consecutive series of 12
shoulders (9 female, 2 male, one bilateral,
mean age 56 years) was staged according to
the Cruess classification and included five
Stage III, 6 Stage IV, and one Stage V. All
procedures were performed on an
outpatient basis. The average procedure
time was 41 minutes (range 23 to 62 min),
blood loss was less than 100mL, no patient
required transfusions peri-operatively and
no complications were encountered. At an
average follow up of 30 months, all patients
reported significant pain relief. Visual
analogue scales improved from 75 to 16 at
the time of final evaluation. The mean
Western Ontario Osteoarthritis of the
Shoulder index score significantly improved
from 1421 preoperatively to 471
postoperatively. The mean Shoulder Score
Index score improved from 24
preoperatively to 75 postoperatively. The mean
Constant score improved from 23
preoperatively to 62. Forward elevation
improved from a mean of 94° to 142° (P <
.001). External rotation improved from a
mean of 28° to 46° (P < .001). All
postoperative radiographs showed solid
fixation of both implant components and no
evidence of periprosthetic loosening,
osteolysis, or device migration.

In a retrospective case series of 19 patients
(16 men, 3 women, 20 shoulders), Sweet et al.
(46) reported their findings on inlay
arthroplasty in young patients (average age
of 48.9 years). Preoperative diagnoses
included osteoarthritis in 16 shoulders and
osteonecrosis in 4. At a mean follow-up of
33 months (range, 17-66 months), the mean
American Shoulder and Elbow Surgeons score
improved from 24.1 to 78.8, the mean
Simple Shoulder Test score improved from
3.95 to 9.3, the mean visual analog scale
score was reduced from 8.2 to 2.1, mean
forward flexion improved from 100 degrees
to 129, and the mean external rotation
changed from 23 to 43 degrees (P<.001 for
all). Radiographic examination showed no
evidence of periprosthetic fracture,
component loosening, osteolysis, or device
failure. The overall patient shoulder self
assessment was 90% poor prior to the
procedure and improved to 75% good to
excellent at final follow-up; 90% of patients
were satisfied with the choice of the
procedure. Three patients experienced
postoperative complications unrelated to the
prosthesis, that included a partial rotator
cuff tear treated with physical therapy, a pre-
existing glenoid wear which was effectively
addressed with arthroscopic debridement
and microfracture, and one infection that
was complicated by a subscapularis rupture
requiring several subsequent surgical
interventions but with retention of the
implant. The authors concluded that inlay
arthroplasty is effective in providing pain
relief, functional improvement, and patient
satisfaction and called it a promising new
direction in primary shoulder arthroplasty
for younger and active patients with earlier
stage disease.

Since 2007, several authors advocated the
use of IA in patients with Hill-Sachs lesions
(7,10,14,25,26,33,38). Potential advantages
were attributed to the anatomically
toured surface reconstruction,
minimizing soft-tissue disruption,
individual sizing, avoiding the limitations of autograft tissue, conservation of bone stock,
short operative time, no associated graft
resorption and subsequent hardware
removal, and lack of disease transmission.
Moros and Ahmad presented a case report
with 2 years follow-up and reported full arm
function with no pain, instability, clicking,
catching, or dislocation. Range of motion
was without limitations and the patient had
returned to full work duties as a porter (33).

In 2015, McKenna et al. (30) published
their rational for outpatient treatment of
compensated cuff arthropathy using inlay
arthroplasty with subscapularis
preservation. Using strict early disease stage
selection criteria and addressing all primary
and secondary pain generators, the authors
concluded that the use of humeracromial IA
in compensated cuff arthropathy has
distinct advantages as the technique
preserves the glenohumeral joint and avoids
the bone loss and complications associated
with stemmed arthroplasty. A deltoid
splitting approach may reduce the risk of
iatrogenic muscle imbalance leaving the
subscapularis tendon intact. The outpatient
procedure enabled patients to undergo an
accelerated recovery and rehabilitation with
emphasis on the deltoid driven functional
compensation. Detailed results on their first
50 subjects treated since 2007 are pending
to date.

Most recently, Davis et al. (9) published
their series of 9 patients treated with total
shoulder arthroplasty combined with inlay
glenoid components for glenoid deficiency.
Four glenoids were classified as Walch type
A2, 2 as type C, and 3 were unable to be
classified. At a 34 month follow-up, seven
patients (4 female and 3 male patients; 9
shoulders) with a mean age of 66 years
showed a statistically significant increase in
range of motion, decrease in pain scores (8
points to 1 point), and improvement in
Single Assessment Numeric Evaluation
scores (31.7% to 89.4%). The mean patient
satisfaction score was 8.6 points on a 10-
point scale. The authors concluded that
management of the glenoid with severe
retroversion or medial bone loss remains a
challenging procedure at all levels of surgical
expertise. Based on their 2-year follow-up,
total shoulder arthroplasty with a mini
glenoid component may be an option to
address a glenoid deficiency and offer
adequate pain relief and functional results.
Our own experience with stemless total shoulder arthroplasty using non-spherical humeral head resurfacing and inlay glenoid replacement has been very encouraging. In the ongoing prospective study, a total of 70 patients (74 shoulders) were treated for advanced glenohumeral arthritis. 38 reached their 2 year follow-up mark. Of those, 2 have been lost to follow-up and 2 did not consent to participate further. Thus 34 patients (36 shoulders, 20 male, 14 female) have reached a mean follow-up of 30 months (24-39 months). Their mean age was 65.9 years (range 45 – 81 years). All clinical outcomes scores showed statistically significant improvements (p<0.001): The mean ASES Score improved from 27.9 - 75.4, the Constant Score improved from 26.9 - 73.0, and the WOOS Index improved from 29.2 - 82.9. Range of motion improved in all dimensions particularly for forward flexion from 102° to 155° and internal rotation from the hip pocket to L3. The VAS Pain Score improved from 7.8 to a mean of 1.4. Patient satisfaction at last follow-up was excellent. All surgeries were performed on an outpatient or 23 hour admission basis. No patient required a transfusion. One patient suffered from a deep infection resulting in glenoid component loosening which was removed. Aside from this complication, radiographs showed no evidence of component loosening or migration. A subset of these patients demonstrated remarkable functional performance at a competitive level of bodybuilding or powerlifting. Five male athletes with an average age of 45.6 years (range 25-57) were prospectively followed. All had advanced glenohumeral arthritis and expressed a strong desire to continue their sport. All were treated utilizing stemless non-spherical resurfacing of the HH combined with an inlay glenoid. There were no blood transfusions and all cases were performed on an outpatient patient basis. The mean follow-up was 31 months (range, 16 - 51). The average ASES score improved from 26 to 93. The mean WOOS score improved from 18 to 87. The mean VAS pain score went from 9 to 1, mean forward flexion increased from 115° to 135°, mean external rotation from 30° to 60°; the preoperative internal rotation allowed patients to reach sacrum levels which improved to lumbar level 3 post-surgery. Four out of five patients assessed their shoulder as poor prior to surgery which improved to good to excellent in all subjects at follow-up. Radiographic assessment revealed no evidence of component loosening, glenoid migration, or evidence of device failure. All patients were satisfied with the choice of the procedure with 4 of the 5 reported to have returned to at least moderate weight lifting activities. One patient required an arthroscopic capsular release for arthrofibrosis which significantly improved function. In this difficult patient population, stemless non-spherical humeral head resurfacing along with an inlay glenoid has been a reliable and effective option for the management of symptomatic osteoarthritis and allowed athletes to return to their sport. The risk for future prosthetic problems or other complications appears less likely than with standard TSA although longer follow-up is necessary.

### Conclusions

Current trends in shoulder arthroplasty have marginalized joint preservation despite a significant increase in volume and a tendency towards younger patients. The predominant use of non-spherical, non-anatomic solutions with stemmed total and reverse shoulder arthroplasty combined with a lack of distinction between inlay and onlay resurfacing procedures turned the specialty away from individual patient decisions and created a conventional treatment spectrum. Inlay arthroplasty shows great promise both from a biomechanical and clinical perspective to offer an individual alternative in primary arthroplasty. Patients may benefit from tissue preservation and a less invasive procedure that avoids the risks, and technical challenges associated with stemmed procedures. Respecting the humeral head geometry mismatch and avoiding glenohumeral joint volume alterations, inlay arthroplasty may become a new path for high demand and sedentary patients alike. However, larger procedure volumes have to be validated through registry and literature reports in order substantiate the presumed advantages.

### References


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