Current Trends in Shoulder Replacement: The Rational for Inlay Arthroplasty

Gregory G Markarian[1], Aboul Deng Bab[2], John W Uribe[3]

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.

[1]OAN Sportsmedicine, Naperville, Il
[2]Atlantic University, School of Medicine
[3]Professor and Chairman, Department of Orthopaedic Surgery, Herbert Wertheim School of Medicine, Florida International University

Address of Correspondence
Dr. Gregory G. Markarian, MD, FACS
OAN Sportsmedicine 10 West Martin Ave Suite 50
Naperville, IL 60540
Email:- drgmark@hotmail.com

Dr. Gregory G Markarian

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.

Patient Age

From 2000 to 2011, the AAOS report (2) showed a 5% increase in total shoulder replacement in patients between 45 – 64 years old (29 –34%), whereas patients 65 – 84 years essentially remained unchanged with a 1% reduction over the same period. The proportion of partial shoulder replacements in middle-aged patients increased by 10% (25 - 35%) (2). US inpatient sample estimates showed that 53% of all patients treated with reverse total shoulder arthroplasty were less than 75 years old. The same applied for 50% of total shoulder arthroplasty (TSA) and 32% of hemiarthroplasty (43).

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 hemi onlay resurfacing in patients under 55 years was 10.4, compared to 8.1 in the 65-74 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

return to sports was significantly better after TSA compared with HA. In addition, the HA patients had significantly more pain, worse surgical satisfaction, and a decreased ability to return to high upper extremity use sports.

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 58mm. 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 intraoperative, 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 contoured 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

1. Amstutz HC, Sew Hoy AL, Clarke IC (1981)'UCLA anatomic total shoulder arthroplasty. ' Clin Orthop Rel Re,s 155, pp. 7-20.

2. Annual Incidence of Common Musculoskeletal Procedures and Treatment. Department of Research and Scientific Affairs. American Academy of Orthopaedic Surgeons (AAOS 2014) http://www.aaos.org/research/stats/CommonProceduresTreatments-March2014.pdf

3. Boileau P, Walch G (1997) 'The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design.' J Bone Joint Surg, 79B(5), pp. 857- 865.

4. Boileau P, Sinnerton RJ, Chuinard C, Walch G (2006) 'Arthroplasty of the shoulder.' J Bone Joint Surg Br, 88(5), pp. 562-575.

5. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A (2005) 'Acomparison of pain, strength, range of motion, and functional outcomes afterhemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. A systematic review and meta-analysis.' J Bone Joint Surg Am, 87(9), pp. 1947-1956.

6. Büchler P, Farron A (2004) 'Benefits of an anatomical reconstruction of the humeral head during shoulder arthroplasty: a finite element analysis.' Clin Biomech Bristol, 19(1), pp. 16-23.

7. Bushnell BD, Creighton RA, Herring MM (2008) 'Bony instability of the shoulder.' Arthroscopy, 24(9), pp. 1061-73.

8. Clarke IC, Gruen TAW, Sew Hoy A, Hirschowitz D, Maki S, Amztutz HC (1979) "Problems in gleno-humeral surface replacements- real or imagined?' Eng Med, 8, pp. 161- 175.

9. Davis DE, Acevedo D, Williams A, Williams G (2016)0' Total shoulder arthroplasty using an inlay mini-glenoid component for glenoid deficiency: a 2-year follow-up of 9 shoulders in 7 patients.' J Shoulder Elbow Surg, 25(8), pp. 1354-1361.

10. Dawson CK, Rolf RH, Holovacs T (2008) 'Management of localized humeral head defects in the athlete. 'Oper Tech Sports Med, 16, pp. 14-20.

11. Dillon MT, Ake CF, Burke MF, Singh A, Yian EH, Paxton EW et al (2015) 'The Kaiser Permanente shoulder arthroplasty registry: results from 6,336 primary shoulder arthroplasties.' Acta Orthop, 86(3), pp. 286-292.

12. Gagliano JR, Sarah M, Helm SM, Colbath GP, Przestrzelski BT, Desjardin JD et al. (2015) 'Comparison of Onlay vs. Inlay Glenoid Prosthetic Design Survivorship Characteristics in Total Shoulder Arthroplasty.' Annual Meeting, Orthopaedic Research Society.

13. Garcia GH, Liu JN, Mahony GT, Sinatro A, Wu HH, Craig EV, Warren RF et al. (2016) 'Hemiarthroplasty Versus Total Shoulder Arthroplasty for

Shoulder Osteoarthritis: A Matched Comparison of Return to Sports.' Am J Sports Med. pii: 0363546516632527. [Epub ahead of print]

14. Grondin P, Leith J (2009) 'Case series: Combined large Hill-Sachs and bony Bankart lesions treated by Latarjet and partial humeral head resurfacing: a report of 2 cases.' Can J Surg, 52(3), pp. 249-54.

15. Gunther SB, Lynch TL, O'Farrell D, Calyore C, Rodenhouse A (2012) 'Finite elementanalysis and physiologic testing of a novel, inset glenoid fixation technique.' J Shoulder Elbow Surg, 21(6), pp. 795-803.

16. Habermeyer P, Ebert T(1999)' Current status and perspectives of shoulderreplacement.' Unfallchirurg, 102(9), pp. 668-683.

17. Hammond G, Tibone JE, McGarry MH, Jun BJ, Lee TQ (2012) 'Biomechanical comparison of anatomic humeral head resurfacing and hemiarthroplasty in functional glenohumeral positions.' J Bone Joint Surg Am, 94(1), pp. 68-76.

18. Harrold F, Wigderowitz C. (2012) 'A three-dimensional analysis of humeral head retroversion.' J Shoulder Elbow Surg 21, pp. 612-617.

19. Hawi N, Tauber M, Messina MJ, Habermeyer P, Martetschläger F (2016) 'Anatomicstemless shoulder arthroplasty and related outcomes: a systematic review.' BMC Musculoskelet Disord. 17(376), pp. 1-10.

20. Hertel R, Knothe U, Ballmer FT (2002) 'Geometry of the proximal humerus and implications for prosthetic design." J Shoulder Elbow Surg 11, pp. 331-318.

21. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S (1992) 'The normal glenohumeral relationships.' J Bone Joint Surg, 76A(4), pp. 491-500.

22. Jun B-J, Iannotti JP, McGarry MH, Yoo JC, Quigley RJ, Lee TQ. (2013) 'The effects of prosthetic humeral head shape on glenohumeral joint kinematics: a comparison of non-spherical and spherical prosthetic heads to the native humeral head.' J Shoulder Elbow Surg, 22, pp. 1423-1432.

23. Jun BJ, Lee TQ, McGarry MH, Quigley RJ, Shin SJ, Iannotti JP (2016) 'The effects of prosthetic humeral head shape on glenohumeral joint kinematics during humeral axial rotation in total shoulder arthroplasty. 'J Shoulder Elbow Surg, 25(7), pp. 1084-1093.

24. Kim SH, Wise BL, Zhang Y, Szabo RM (2011) 'Increasing incidence of shoulderarthroplasty in the United States.' J Bone Joint Surg Am, 21,93(24), pp. 2249-2254.

25. Kösters C, Schliemann B, Raschke M. Endoprothetik nach Trauma (2010) Trauma Berufskrankh, 12, pp. 47–52.

26. Lenarz C, Shishani Y, Gobezie R (2011) 'Surface Replacement: The Hemicap Solution.' Semin Arthro, 22, pp. 10-13.

27. Levy O, Copeland SA (2001) 'Cementless surface replacement arthroplasty of the shoulder. 5- to 10-year results with the Copeland mark-2 prosthesis.' J Bone Joint Surg Br, 83(2), pp. 213-221.

28. Levy O, Copeland SA (2004) 'Cementless surface replacement arthroplasty (Copeland CSRA) for osteoarthritis of the shoulder. 'J Shoulder Elbow Surg, 13(3), pp. 266-271.

29. Levy O, Tsvieli O, Merchant J, Young L, Trimarchi A, Dattani R et al. (2015) 'Surface replacement arthroplasty for glenohumeral arthropathy in patients aged younger than fifty years: results after a minimum ten-year follow-up.' J Shoulder Elbow Surg, 24(7), pp. 1049-1060.

30. McKenna RW, Chandler T (2015) 'Outpatient Treatment of Compensated Cuff Arthropathy Using Inlay Arthroplasty with Subscapularis Preservation.' Tech Shoulder Elbow Surg, 16(4), pp. 115-125.

31. McPherson EJ, Friedman RJ, An, YH, Chokesi R, Dooley L (1994) 'Anthropometric study of normal glenohumeral relationships.' J Shoulder Elbow Surg, 6, pp. 105-112.

32. Mechlenburg I, Amstrup A, Klebe T, Jacobsen SS, Teichert G, Stilling M (2013) 'The Copeland resurfacing humeral head implant does not restore humeral head anatomy. A retrospective study.' Arch Orthop Trauma Surg, 133(5), pp. 615-619.

33. Moros C, Ahmad CS (2009)' Partial humeral head resurfacing and Latarjet coracoid transfer for treatment of recurrent anterior glenohumeral instability.' Orthopedics, 32(8), pp. 602-605.

34. Mullett H, Levy O, Raj D, Even T, Abraham R, Copeland SA (2007) 'Copeland surface replacement of the shoulder. Results of an hydroxyapatite-coated cementless implant in patients over 80 years of age.' J Bone Joint Surg Br, 89(11), pp. 1466-1469.

35. National Joint Replacement Registry, The Australian Orthopaedic Association. Hip, Knee and Shoulder Arthroplasty, Supplementary Report 2016 https://aoanjrr.sahmri.com/annual-reports-2016.

36. Neer CS (1955) 'Articular replacement of the humeral head.'J Bone Joint Surg, 37A(2), pp. 215-228.

37. Padegimas EM, Maltenfort M, Lazarus MD, Ramsey ML, Williams GR, Namdari S (2015) 'Future patient demand for shoulder arthroplasty by younger patients: national projections.' Clin Orthop Relat Res, 473(6), pp. 1860-1867.

38. Patel RV, Apostle K, Leith JM, Regan WD (2008) 'Revision arthroscopic capsulolabral reconstruction for recurrent instability of the shoulder.' J Bone Joint Surg Br, 90(11), pp.1462-7.

39. Pinkas D, Wiater JM, Spencer EE Jr, Edwards TB, Uribe JW, Declercq G, Murthi AM, Hertel R (2015) 'Shoulder prosthetic arthroplasty options in 2014: what to do and when to do it.' Instr Course Lect, 64, pp. 193-202.

40. Radnay CS, Setter KJ, Chambers L, Levine WN, Bigliani LU, Ahmad CS (2007) 'Total shoulder replacement compared with humeral head replacement for the treatment of primary glenohumeral osteoarthritis: A systematic review.' J Shoulder Elbow Surg 16, pp. 396–402.

41. Sandow MJ, David H, Bentall SJ (2013) 'Hemiarthroplasty vs total shoulder replacement for rotator cuff intact osteoarthritis: how do they fare after a decade?' J Shoulder Elbow Surg, 22(7), pp. 877-885.

42. Sarrafian SK (1983) 'Gross and functional anatomy of the shoulder.' Clin Orthop, 173, pp. 11-19.

43. Schairer WW, Nwachukwu BU, Lyman S, Craig EV, Gulotta LV. (2015) 'National utilization of reverse total shoulder arthroplasty in the United States.' J Shoulder Elbow Surg, 24(1), pp. 91-97.

44. Schwartz BE, Savin DD, Youderian AR, Mossad D, Goldberg BA (2015) 'National trends and perioperative outcomes in primary and revision total shoulder arthroplasty: Trends in total shoulder arthroplasty.' Int Ortho,p 39(2), pp. 271-276.

45. Stilling M, Mechlenburg I, Amstrup A, Soballe K, Klebe T (2012) 'Precision of novel radiological methods in relation to resurfacing humeral head implants: assessment by radiostereometric analysis, DXA, and geometrical analysis.' Arch Orthop Trauma Surg, 132(11), pp. 1521-1530.

46. Sweet SJ, Takara T, Ho L, Tibone JE (2015) 'Primary partial humeral head resurfacing:outcomes with the HemiCAP implant.' Am J Sports Med, 43(3), pp. 579-587.

47. Uribe JW, Botto-van Bemden A (2009) 'Partial humeral head resurfacing forosteonecrosis.' J Shoulder Elbow Surg, 18(5), pp. 711-716.

48. Walch G, Boileau P (1999) 'Prosthetic adaptability: a new concept for shoulder arthroplasty.' J Shoulder Elbow Surg, 8(5), pp. 443-451.

49. Wataru S, Kazuomi S, Yoshikazu N, Hiroaki I, Takaharu Y, Hideki Y (2005) 'Three-dimensional morphological analysis of humeral heads.' Acta Orthopedica, 76(3), pp. 392-396.

50. Zumstein V, Kraljevic´ M, Hoechel S, Conzen A, Nowakowski AM, Müller-Gerbl M (2014) 'The glenohumeral joint—a mismatching system? A morphological analysis of the cartilaginous and osseous curvature of the humeral head and the glenoid cavity. ' J Orthop Surg Res, 9,34, pp. 1-6.

Conflict of Interest: NIL
Source of Support: NIL

How to Cite this Article

Markarian GG, Bab AD, Uribe JW. Current Trends in Shoulder Replacement: The Rational for Inlay Arthroplasty. Acta of Shoulder and Elbow Surgery Oct - Dec 2016;1(1):14-19