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ORIGINAL ARTICLE

Shoulder arthroplasty using mini-stem humeral components and a lesser tuberosity osteotomy

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Abstract

Purpose To determine whether lesser tuberosity osteotomy (LTO) and mini-stem humeral components (MSHCs) can be safely and effectively used together in total and hemi-shoulder arthroplasty (TSA/HHA).

Methods This is a retrospective review of consecutive patients who underwent anatomic TSA/HHA utilizing combined LTO/MSHC with minimum 2-year follow-up. Six-week and final radiographs, range of motion, pain scores, and selected outcome measures were assessed.

Results Seventy five shoulders with mean follow-up of 27.8 months (24–50 months) were analyzed. Sixty-seven (89.3%) shoulders had uneventful LTO healing. There were five (6.67%) LTO failures, one (1.33%) fibrous union, and two (2.67%) osteotomies that had displaced > 4 mm at 6 weeks; four of the five failures required open repair, including one converted to reverse TSA. The other failure, the fibrous union, and the two displaced osteotomies were without clinical deficits and elected for non-operative management. One patient required intraoperative conversion to a long stem due to concern that metaphyseal bone integrity was compromised, in part, by the LTO. Four (5.33%) stems subsided, with one of them also being frankly loose and requiring revision, while the other three were asymptomatic, not requiring treatment. No other stems were judged to be loose. Mean ASES, SANE, VAS, forward flexion, external rotation, and internal rotation all improved significantly ($p < 0.001$ for all).

Conclusions LTO/MSHC use is appropriate for TSA/HHA, achieving pain relief and functional improvement. Component loosening appears uncommon at early follow-up. Long-stem components should be available in case the metaphyseal bone is compromised. When performed properly, LTO/MSHC use is a safe and effective surgical strategy.

Keywords Shoulder · Arthroplasty · Lesser tuberosity · Osteotomy · Stem · Humerus

Introduction

Shoulder arthroplasty is a common treatment for glenohumeral arthritis, with implant survival rates above 90% after 10 years [29]. While a few authors have advocated total shoulder arthroplasty (TSA) through the rotator interval to preserve the subscapularis attachment [5, 9], in general, mobilization of the subscapularis from its attachment on the lesser tuberosity is necessary [23]. However, the subscapularis repair may fail to heal, leading to subscapularis insufficiency—a condition marked by pain, weakness, anterior instability, and early glenoid prosthetic loosening [14]. Subscapularis insufficiency is the most common cause of revision surgery for failed anatomic arthroplasty [19]. In addition to subscapularis insufficiency, more subtle changes with partial tear, fatty infiltration despite complete healing, and residual weakness from non-anatomic reattachment can cause more subtle abnormalities in up to two-thirds of postoperative patients [14]. In an attempt to avoid these issues, an alternative has emerged to subscapularis tenotomy or subscapularis peel. The lesser tuberosity osteotomy (LTO) has the potential advantages of preserving the muscle–tendon–bone unit, allowing for bone-to-bone healing [6, 7, 23] and the ability to visualize the healing process via standard radiographs or CT [4] (Fig. 1). A systematic review of several cadaveric studies demonstrated a

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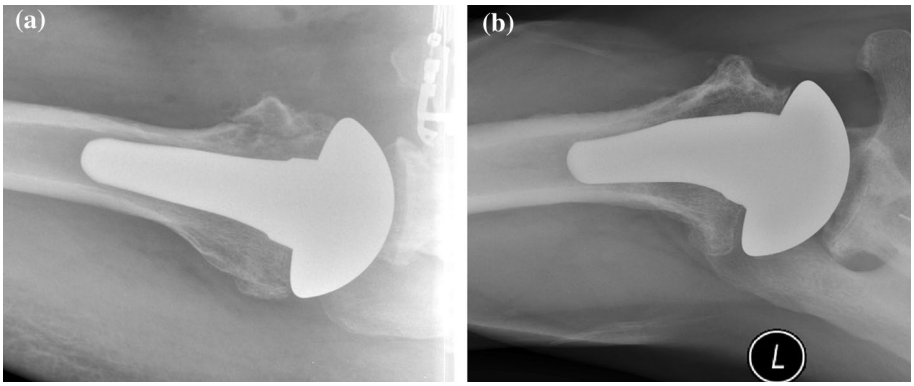

Fig. 1 Shoulder radiographs showing **a** mini-stem humeral component with anatomically reduced lesser tuberosity osteotomy 2 weeks postoperatively, **b** mini-stem humeral component with bony union of lesser tuberosity osteotomy 2 years postoperatively

biomechanical advantage with LTO compared to subscapularis peel or tenotomy [26], and a small retrospective study suggests improved clinical results with LTO [23]. However, a prospective study comparing the two techniques indicated no significant differences in function at 24 months post-op [10]. A recent systematic review by Choate et al. showed that although subscapularis healing and integrity appear to favor the LTO, no significant difference in musculotendinous integrity or clinical outcomes was demonstrated [2].

Another aspect of shoulder arthroplasty that has seen recent changes is the surgical implant used in the procedure. Traditionally, a longer-stemmed humeral component was used in total shoulder arthroplasty, with a high rate of success and low incidence of humeral loosening (Fig. 2a). However, this approach may not be feasible in cases where patients have an ipsilateral elbow replacement or humeral deformity, where placement of a longer, diaphyseal-fit stem is precluded [8]. Furthermore, stress shielding from implants with diaphyseal cortical fixation has been observed with these implants [16]. Recently, mini-stem humeral components (MSHCs) have emerged as an alternative to address the aforementioned limitations of the standard-length stem prosthesis (Fig. 2b). These designs rely on fixation in the metaphyseal cancellous bone with the purported benefits of decreased bone removal, decreased stress shielding, ease of revision, and ease of treatment of peri-prosthetic fracture [8, 25]. It remains to be seen whether this proximal fixation will lead to increased humeral prosthetic loosening long term; early results with MSHC show mixed results, with some comparable to those of standard-length humeral components [8, 24] and some with a loosening rate up to 8.7% at 24 months [1].

Given that the MSHC relies on proximal, metaphyseal fixation, and LTO can remove a significant part of the anterior, metaphyseal osseous anatomy, some have voiced that LTO in combination with MSHC is contraindicated. However, the senior authors have combined these techniques to take advantage of the potential benefits of both. This is the first description of combining MSHC with LTO, with analysis of the short-term clinical outcomes (minimum 2-year follow-up), radiographic assessment of LTO healing, prosthetic loosening or subsidence, and an analysis of failures. We hypothesized that combining MSHC with LTO will result in clinical and radiographic outcomes as good as or better than the published results of more established techniques.

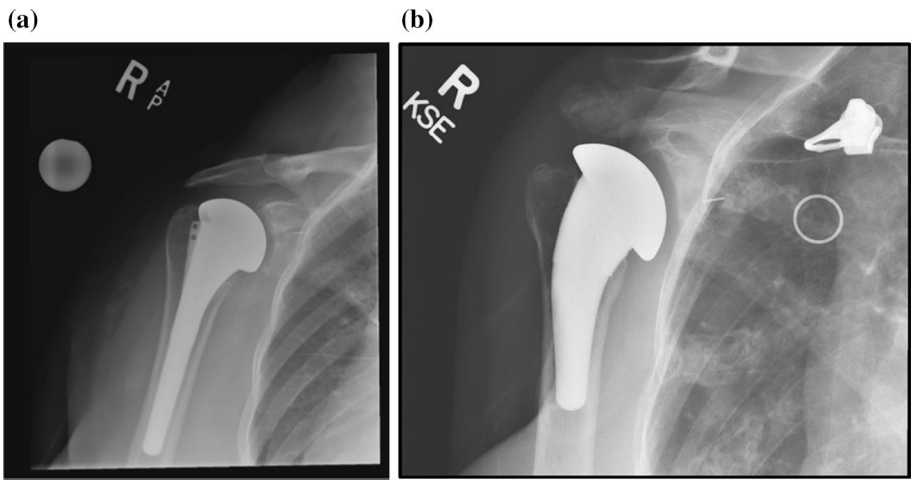

Fig. 2 Shoulder radiographs showing **a** right shoulder with standard-length stem humeral implant, **b** right shoulder with mini-stem humeral component

Materials and methods

Participants

This was a retrospective cohort study conducted at two medical centers, evaluating patients treated by two shoulder and elbow fellowship-trained surgeons (P.S.J and G.E.G.). Patients with glenohumeral osteoarthritis, avascular necrosis of the humeral head, or rheumatoid arthritis, seen at either institution and treated with an anatomic shoulder arthroplasty, either a hemiarthroplasty (HHA) (CPT code 23470) or a total shoulder arthroplasty (TSA) (CPT code 23472), performed by either of the senior authors between March 2011 and March 2014 were eligible. The primary surgical indications and their corresponding *n* values are illustrated in Table 1. These patients are part of a multicenter shoulder arthroplasty database, and a subset of the patients included here have been analyzed in a prior publication evaluating a different topic [15]. The inclusion criteria for the present study included patients between the ages of 18 and 99 (actual age range 44–88) who received either an HHA or TSA, using both MSHC and LTO, with minimum postoperative clinical and radiographic follow-up of 2 years. Exclusion criteria included rotator cuff-deficient shoulders, revision surgery, reverse total shoulder arthroplasty, and clinical or radiographic follow-up less than 2 years. All patients were instructed to adhere to the same postoperative rehabilitation protocol under the supervision of a physical therapist. This consisted of sling use for 6 weeks, with removal only for dressing, bathing, and three to five time-per-day, supine, passive, well-arm-assisted range of motion within defined limits of the subscapularis safe zone starting postoperative day one (maximum forward flexion 140° and maximum external rotation 40°). At 6 weeks, the sling was discontinued, and the patient started stretching beyond the subscapularis safe-zone limits, internal rotation was initiated, and active range of motion commenced. All data collection and analysis was performed with approval by the institutional review board (study number Pro00053203).

Table 1 Indications for index operation

Indication for TSA/HHA	*n*
Osteoarthritis	69
Avascular necrosis	5
Rheumatoid arthritis	1
Total	75

TSA total shoulder arthroplasty, *HHA* hemiarthroplasty

Clinical evaluation

All patients in the study underwent evaluation of the affected shoulder preoperatively and at postoperative intervals of 6 weeks, 6 months, 1 year, 2 years, and yearly thereafter. Active and passive range of motion and visual analog pain scores were assessed and documented in the patient encounter note at each visit. To statistically evaluate internal rotation at neutral position, a numerical scheme was used that converted traditional IR levels (e.g., T8, L4) into corresponding numbers, starting at 1 for T1 and ending at 22 for S5 and below. All patients were given shoulder self-assessment questionnaires to complete during their office visit, corresponding to the American Shoulder and Elbow Surgeons (ASES) score and Single Alphanumeric Evaluation (SANE) score.

Outcome evaluation

Subjective clinical outcomes were measured with three patient-driven questionnaires. The first was a simple visual analog scale (VAS) pain score, with patients being asked to describe their level of pain in the affected joint on a scale from 0 to 10, with 0 being no pain and 10 being the worst pain imaginable. The second scoring system, the ASES score [19], which corresponds to pain and proficiency with activities of daily living, has previously been validated [12, 13, 21]. The score, which is out of 100, derives 50 points from pain and 50 points from performance of activities of daily living [20]. The final clinical outcome measurement was the SANE score [17, 30], which is derived wholly from the patient's own written answer to the question of "how would you rate your shoulder today as a percentage of normal (0 to 100% scale with 100% being normal)?" This scoring system correlates well with the ASES score [3, 17, 30].

Radiographic evaluation

Preoperative and minimum 6-week, 6-month, 1-year, and 2-year postoperative radiographs were taken of all patients as part of clinical standard of care. These radiographs included a Grashey true anteroposterior view in neutral humeral rotation and an axillary lateral view. Radiographic analysis was performed, blinded by all authors, for potential MSHC complications, including loosening, subsidence, and fracture [27, 28]. The modified Gruen scoring system, described by Sanchez-Sotelo et al. [22], was primarily used to assess the status of the humeral implant. A stem was considered to be "at risk for loosening" if it had radiolucent lines in 3 or more contiguous zones or had subsided [28]. The LTO was assessed for osteotomy union, fibrous union, malunion (defined here as displacement > 4 mm), or failure. 4 mm was chosen based on the cadaveric study by Williams

et al. [31] that concluded that greater than 4 mm of malposition of the prosthesis may predispose to an increased incidence of rotator cuff tears; the clinical implications of an LTO healing with some displacement are unclear. Glenoid loosening was graded using the Lazarus scale for TSA [11], and glenoid erosion was evaluated for HHA patients [18] on a binary scale.

Surgical technique

All patients treated by G.E.G. had anatomic shoulder arthroplasty (5 HHA and 35 TSA) with one of two similar MSHC prostheses (Tornier Aequalis Ascend or Tornier Aequalis Ascend PTC) (Tornier, Bloomington, MN). All patients treated by P.S.J. had anatomic shoulder arthroplasty (1 HHA, 34 TSA) with one of three similar MSHC prostheses (Tornier Aequalis Ascend, BioMet Comprehensive Total Shoulder System, or Tornier Aequalis Ascend Flex) (Biomet, Warsaw, IN). All implants have the same metaphyseal fit-and-fill contour and nearly identical instrumentation, with the differences being the BioMet, Ascend PTC and Ascend Flex implants have a strip of proximal titanium ingrowth coating in addition to the grit-blasted surface of the rest of the stem, and the Ascend Flex has a taper that can accommodate a humerosocket tray for conversion to reverse TSA. Implant choice was made by the surgeon. All glenoid implants were pegged, all polyethylene designs with an uncemented, fluted "Corti-Loc" central peg and three peripheral cemented pegs. The Affiniti, Perform, and BioMet glenoid systems are similar, with the differences being that the Perform has variable backside radii of curvature for minimal bone removal, is typically implanted with cannulated reaming, and has a higher humeral head/glenoid radius of curvature mismatch.

After routine soft tissue biceps tenodesis to the upper portion of the pectoralis major, the lesser tuberosity osteotomy was made with a 1- or 1.5-inch curved osteotome. The osteotomy starts in the deepest portion of the biceps groove and aims for the anatomic neck medially to remove the entire lesser tuberosity. G.E.G. routinely dissects the anterior capsule from the subscapularis tendon and then resects this tissue from the coracoid to the six-o'clock position on the glenoid (40 patients). The remaining (35) patients performed by P.S.J. had the capsule released from the humerus and glenoid attachments, but not resected.

The LTO is repaired using a modification of the technique described by Gerber [6] with four sutures around the fragment and then through the bone bed and around the biceps groove. An additional suture is placed around the implant and brought up medial to the lesser tuberosity osteotomy as a horizontal mattress. A soft tissue suture is tied across the lateral apex of the rotator interval from the upper subscapularis attachment to the anterior–lateral edge of the supraspinatus, re-approximating the tissues normally connected by the biceps sling.

Statistical analysis

Data were collected preoperatively and at postoperative intervals of 6 weeks, 6 months, 1 year, 2 years, and yearly thereafter. Pre- and postoperative data (minimum 2-year follow-up) were compared using the Student's two-tailed t test. p values < 0.05 were considered significant.

Results

Average patient age at index operation was 68.3 years, and average follow-up was 27.8 months (range 24–50 months). There were 69 shoulders treated for glenohumeral osteoarthritis, five for avascular necrosis of the humeral head, and one for rheumatoid arthritis (Table 1). Overall, 75 (51.4%) of 146 shoulders had minimum 2-year clinical and radiographic follow-up. No stems required cementation and there were no infections. One patient during the study period required intraoperative conversion to a diaphyseal-fit stem due to concern that the proximal metaphyseal bone integrity was compromised, in part, by the LTO.

Given the retrospective nature of this study, the implant choice was at the discretion of each surgeon. However, due to the similarities between the implant types and surgical technique of both senior authors, we feel it is appropriate to analyze the patients as a group rather than separate analysis based on surgeon, implant type, or TSA versus HHA.

Preoperative mean range of motion was 31.3° of external rotation at 0°, internal rotation at 0° between L5 and S1, and 113° of forward flexion/elevation. Patients had significantly greater active external rotation (57.3°, $p < 0.001$), forward flexion/elevation (153°, $p < 0.001$), and internal rotation (T11, $p < 0.001$) at most recent follow-up. Mean preoperative ASES, SANE, and VAS pain scores were 39.0, 40.0, and 5.83, respectively. At most recent follow-up, these functional outcome scores improved to mean ASES score of 87.9 ($p < 0.001$), SANE score of 89.0 ($p < 0.001$), and VAS pain score of 0.793 ($p < 0.001$). Clinical outcomes are summarized in Table 2.

Grashey AP and axillary lateral shoulder radiographs taken 6 weeks after surgery and at final clinical follow-up were analyzed. There were five (6.67%) LTO failures, one (1.33%) fibrous union, and two (2.67%) osteotomies that had displaced > 4 mm at 6 weeks; four of the five failures required open repair, including one converted to reverse TSA. The other failure, the fibrous union, and the two displaced osteotomies were without clinical deficits and elected for non-operative management. Two of the failures were traumatic, and three were due to non-compliance to

Table 2 Preoperative and postoperative range of motion and outcomes scores

	Preoperative	Postoperative	*p* value
External rotation	31.3°	57.3°	< 0.001
Forward flexion	113°	153.3°	< 0.001
Internal rotation	L5-S1	T11	< 0.001
ASES score	39.0	87.9	< 0.001
SANE score	40.0	89.0	< 0.001
VAS pain score	5.83	0.79	< 0.001

ASES American Shoulder and Elbow Surgeons, *SANE* single alphanumeric evaluation, *VAS* visual analog scale

Table 3 Six-week and final postoperative radiographic evaluation

	6 weeks	Final
Osteotomy status	67 (89.3%) bony union 1 (1.33%) fibrous union 2 (2.67%) malunion 5 (6.67%) failures	67 (89.3%) bony union 1 (1.33%) fibrous union 2 (2.67%) malunion 5 (6.67%) failures
Number and location of humeral lucencies (Sanchez-Sotelo)	0	Per zone: 4 × 1, 3x4, 2x5, 4x6, 11x7, 16x8
Number and location of glenoid lucencies (Lazarus)	0	Per zone: 1x1, 1x2, 2x5
Number of loose humeral stems	0	1 (1.33%)
Number of "at-risk" humeral stems	0	5 (6.67%)
Number of subsided stems	0	4 (5.33%)

postoperative rehabilitation protocol. At most recent follow-up of the five LTO failures, one fibrous union, and two displaced osteotomies, the average ASES score was 89.6, SANE 90.6, and VAS 0.250, compared to average ASES of 87.6, SANE of 88.8, and VAS of 0.858 in those with uneventful healing of the LTO.

There were no visible stem lucencies, stem loosening, or glenoid loosening at 6 weeks. At final clinical follow-up, there was no evidence of additional osteotomy failures. Twenty-three (30.7%) stems showed lucencies in the modified Gruen zones, and four stems (5.33%) were judged to be at risk of loosening, but only one (1.33%) showed frank loosening. Further details are illustrated in Table 3. There was no evidence of glenoid component loosening, although four (5.80%) of the glenoid implants showed a lucent line in at least one of the Lazarus zones. Four stems (5.33%) subsided, with one of them also being frankly loose and requiring revision, while the other three were asymptomatic, not requiring treatment. Of the 37 stems implanted with proximal ingrowth coating, one (2.70%) subsided, zero loosened, and one (2.70%) was at risk of loosening. Of the 38 stems implanted without proximal ingrowth coating, three (7.89%) subsided, one (2.63%) loosened, and four (10.5%) were deemed to be at risk of loosening. Of the six HHAs, one (20%) showed noticeable glenoid erosion.

Discussion

Shoulder arthroplasty is a common treatment for glenohumeral arthritis, and different implants and techniques are continuously being introduced. MSHC use has developed as an alternative to the standard-length stem humeral prosthesis, while the LTO is an accepted procedure for mobilization of the subscapularis. MSHC use preserves bone and provides ease of revision, and the LTO preserves the muscle–tendon–bone interface, allowing bone-to-bone healing and radiographic monitoring. However, given that the MSHC relies on proximal, metaphyseal fixation and LTO can remove a significant part of the anterior, metaphyseal osseous anatomy, some have postulated that LTO in combination with MSHC may be contraindicated. We believe that our data support that it is possible to take advantage of both techniques and achieve similar results, at 2-year minimum follow-up, to those seen with traditional methods.

The clinical outcome scores for our combined MSHC/LTO cohort (ASES = 87.9, SANE = 89.0, VAS = 0.79) are comparable to the excellent results for shoulder arthroplasty described in the literature for either technique as used separately [6, 7, 8, 18, 22]. As observed in multiple other shoulder arthroplasty series, range of motion (ROM) in all planes improved significantly, with all postoperative planes of motion near normal (mean FF = 153°, mean ER = 57.3°), although IR range (mean IR = T11) was not restored as reliably. Final radiographic analysis showed lucencies in 23 (30.7%) of the humeral stems (most frequently near the calcar), with four (5.33%) of the stems being judged to be at risk of loosening, but only one (1.33%) of the stems showing frank loosening. Four stems (5.33%) subsided, but only one of the four was symptomatic and required treatment; the one subsided stem that required treatment was also loose. These numbers fall within the published range for other studies of both conventional and short-stem humeral implants [1, 5, 8, 24, 25, 27, 28].

Of the 37 stems implanted with proximal ingrowth coating, one (2.70%) subsided, zero loosened, and one (2.70%) was at risk of loosening. Of the 38 stems implanted without proximal ingrowth coating, three (7.89%) subsided, one (2.63%) loosened, and four (10.5%) were deemed to be at risk of loosening. This is consistent with findings

by Morwood et al. that demonstrated an increased risk of loosening and developing radiolucencies among uncoated MSHCs compared to those with proximal ingrowth coating [15].

There were five (6.67%) lesser tuberosity osteotomy failures seen in our series, all of which occurred during the initial 6-week postoperative period, prior to bony union. Two of the LTO failures were traumatic, and three were due to non-compliance to postoperative rehabilitation protocol. Of these five failures, four required open repair, one of which was later converted to a reverse TSA, and one had no clinical deficits and elected for non-operative management. There was also one fibrous union and two osteotomies with displacement > 4 mm, each of which was asymptomatic, not requiring treatment. Interestingly, mean final ASES (89.6), SANE (90.6), and VAS (0.250) measures for all patients with LTO failure, fibrous union, or displacement were similar to those with uneventful LTO healing, which had ASES (87.6), SANE (88.8), and VAS (0.858). As the osteotomy integrity is easily assessed with plain radiographs, and the retracted tendon is easily found surgically by palpating the bony tuberosity, early awareness of failures and ease of repair likely led to good outcomes even in the LTO failure group. However, the fact that radiographic failures are more apparent with an LTO technique than subscapularis tenotomy or peel could lead to unnecessary surgery. For the patients who had excellent results despite the lesser tuberosity radiographic abnormalities, it is unclear whether these abnormalities would ever have been clinically detected if these patients had tenotomy or peel, where the integrity of the subscapularis is not evident on routine imaging. Given that each of the five LTO failures occurred during the first 6 weeks, prior to bony union, it is possible that the 40° of well-arm-assisted external rotation allowed in the postoperative protocol during this time caused too much stress on the repair and may have predisposed the LTO to failure. The 6.67% failure rate in this study falls within the published range of failure for both LTO and subscapularis peel, which have been shown to have similar clinical outcomes and musculotendinous integrity in the current literature [2].

There are limitations to our study. The retrospective data collection and comparison to historical controls is a potentially limiting factor. The length of follow-up is short term, and we can make no conclusions regarding the long-term success rate of the MSHC/LTO technique at this time. Slightly different stems, surgical techniques, or physical therapy protocols could cause differences in outcomes. The relatively low percentage of patients who returned for final postoperative clinical and radiographic evaluation is a limitation, and it is possible that those who did not return have inferior outcomes compared to those who did. We made every effort to contact our patients, but with a referral practice, many of our patients live out of state or even out of the country and frequently do not follow-up after the one-year appointment.

Strengths of this study include sample size, demographic characteristics, operations performed in a nearly identical fashion by two shoulder and elbow fellowship-trained surgeons, similar implants, identical postoperative protocols, and blinded radiographic evaluation. Given these strengths, we feel that this study is applicable to the overall population of patients who may need shoulder arthroplasty. Future studies include longer-term follow-up with clinical and radiographic outcomes analysis, analysis of the effects of the capsulectomy on overall success of the TSA, and comparing results of the combined MSHC/LTO technique when applied for different primary diagnoses.

The use of MSHC in combination with an LTO is a viable option for shoulder arthroplasty, achieving pain relief and functional improvement. LTO failure is relatively uncommon at early follow-up, and early detection and repair of failures resulted in similar functional outcomes compared to those with uneventful LTO healing in our study. Implant loosening appears to be uncommon at early follow-up, although lucencies and risk of loosening are evident. Long-term radiographic follow-up is essential to monitor for complications of stem loosening and subsidence. Metaphyseal bone preservation is encouraged, and a standard-length stem humeral component should be available as backup, should an overaggressive LTO compromise the metaphyseal bone. We recommend an LTO that does not communicate with the osteotomy of the humeral head. We also recommend strict adherence to designated range-of-motion restrictions to protect the subscapularis until radiographic evidence of osteotomy healing has been documented. When these principles are followed, concomitant use of an LTO and MSHC is a safe and effective surgical strategy.

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Compliance with ethical standards

Conflict of interest None of the authors are designers or receive royalties for any implants used in this study. G.E.G and P.S.J. are paid consultants for Tornier/Wright Medical, the manufacturer of some implants used in the study. G.E.G. is a paid consultant for DJO/Encore.

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