J Shoulder Elbow Surg (2020) 29, S9–S16

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Optimizing humeral stem fixation in revision reverse shoulder arthroplasty with the cement-within-cement technique

R. Allen Gorman II, MD[a], Kaitlyn N. Christmas, BS, CCRC[a], Peter Simon, PhD[a], A. Vincent Hess II, BA[a], Earl E. Brewley Jr, MD[b], Mark A. Mighell, MD[b], Mark A. Frankle, MD[b,*]

[a]*Foundation for Orthopaedic Research and Education, Tampa, FL, USA*
[b]*Florida Orthopaedic Institute, Tampa, FL, USA*

Background: The purpose of this study was to report on the clinical outcomes of patients undergoing revision reverse shoulder arthroplasty (RSA) by the cement-within-cement technique, as well as to identify whether surgical technique can affect subsequent humeral loosening.
Methods: In 98 patients, cemented humeral components that were revised to RSA using the cement-within-cement technique were identified and included in this study. We compared 8 patients in whom humeral stem loosening developed with 90 patients whose stem remained fixed. Preoperative and postoperative radiographs of each patient were downloaded in DICOM (Digital Imaging and Communications in Medicine) format and analyzed in Mimics. The total area of the cement mantle (in square millimeters) and of the stem (in square millimeters), as visualized on 2-dimensional plain films, was measured in each subject on both preoperative and postoperative radiographs. Outcomes at a minimum of 2 years of follow-up were analyzed.
Results: Clinical outcomes were available in 57 patients, with a mean follow-up period of 54 months (range, 21-156 months). Patients demonstrated significantly improved functional outcome scores and shoulder range of motion. In the group without loosening, the mean increase in the cement mantle area was 4380 ± 12701 mm^2 ($P < .0001$). In the group with loosening, the mean increase in the cement mantle area was only 811 ± 4014 mm^2 ($P = .484$).
Conclusions: Use of the cement-within-cement technique for fixation of the humeral component in revision RSA is effective in improving functional outcome scores and shoulder range of motion. Furthermore, these findings suggest that efforts to maximize the cement volume during reimplantation may lessen the chance of humeral stem loosening requiring additional revision.
Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Revision; reverse shoulder arthroplasty; cement within cement; cemented; humeral; bone loss

Revision shoulder arthroplasty is a technically challenging procedure with inconsistent results.[5,24,32,35,36] Studies have reported the advantages of retaining the humeral component[8,35,36]; however, revision of the humeral prosthesis is often necessary in the setting of proximal humeral bone loss, primary humeral implant loosening, periprosthetic fracture, implant malposition, and humeral

This study was determined to be exempt from review by the Western Institutional Review Board.

*Reprint requests: Mark A. Frankle, MD, Florida Orthopaedic Institute, 13020 N Telecom Pkwy, Tampa, FL 33637, USA.
E-mail address: mfrankle@floridaortho.com (M.A. Frankle).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2020.01.094

medialization. A key objective in the revision process is to create a stable foundation for the revision stem while salvaging as much bone stock as possible. In addition, stem extraction and complete removal of the cement may be arduous and can lead to subsequent severe bone loss, cortical perforation, fracture, and risk of thermal injury to the radial nerve.[4,5,15,32,36] Use of reverse shoulder arthroplasty (RSA) has allowed surgeons to overcome many of the difficulties encountered in the revision setting.[1-4,6,9-11,16-18,20,23,25-27,34]

Implantation of a new cemented revision component into a retained cement mantle is a widely accepted technique in revision hip surgery.[12,14,19,21,22,29] Various intraoperative strategies can be used to provide adequate stability of the stem during revision surgery, including using the stem with the largest possible diameter in the existing cement mantle, thereby minimizing the amount of new cement, or implanting the smallest stem possible, allowing for the maximum amount of added cement. However, there is a paucity of literature regarding its application and capability in the shoulder.

The purpose of this study was to determine whether surgical technique affects subsequent humeral loosening, as well as to report on the clinical outcomes of patients undergoing revision RSA by the cement-within-cement technique. We hypothesized that a greater increase in the preoperative-to-postoperative amount of cement coupled with preoperative-to-postoperative stem downsizing would decrease the incidence of humeral loosening.

Methods

Radiographic assessment

In this retrospective cohort analysis, a chart review identified a total of 98 patients treated from 2004 to 2016. The inclusion criteria were patients undergoing revision RSA in the setting of the cement-within-cement technique. Patient demographic characteristics are noted in Table I. Preoperative and postoperative radiographs of each patient were downloaded in DICOM (Digital Imaging and Communications in Medicine) format (Fig. 1) and analyzed in Mimics (version 14.12; Materialise, Leuven, Belgium) (Fig. 2). The standard anteroposterior view was used for measurement. The total area of the cement mantle (in square millimeters) and total area of the humeral stem (in square millimeters), as visualized on 2-dimensional plain films, were measured in each patient on both preoperative and postoperative radiographs. The filling ratio (ie, area of the stem to combined areas of stem and cement) was then calculated for each case. In addition, preoperative-to-postoperative differences between areas of cement, areas of stem, and filling ratios were calculated for all patients.

The study population was further stratified into 2 groups based on the diagnosis of radiographic humeral loosening. Routine postoperative radiographic evaluation included anteroposterior, Grashey, and axillary views. Stems were defined as loose using modified criteria based on the Gruen zones described for cemented stems by Sanchez-Sotelo et al.[13,28] In this system, the humeral stem is divided into thirds and zones 1 to 3 correspond to the lateral aspect of the stem extending from proximal to distal. Zone 4 is at the tip of the stem, and zones 5 to 7 extend from distal to proximal on the medial aspect of the stem. Zone 8 is directly underneath the humeral head. Lines were graded according to size as 1 mm, 1.5 mm, 2 mm, or greater than 2 mm. Group 1 consisted of patients in whom humeral loosening developed after revision RSA (n = 8), and group 2 contained patients who did not show signs of radiographic loosening after revision RSA (n = 90).

Table I Demographic characteristics

	Group 1 (loosening)	Group 2 (no loosening)
No. of patients	8	90
Age, mean (range), yr	59 (43-77)	67 (28-90)
Sex, n	4 M/4 F	35 M/55 F

M, male; *F*, female.

Clinical assessment

Clinical outcomes were available in 57 patients who had a mean follow-up period of 54 months (range, 21-156 months), showed no evidence of radiographic humeral loosening, and did not undergo a second revision surgical procedure. Patient-reported range of motion was obtained in each patient at each follow-up visit. Additional postoperative functional assessments including American Shoulder and Elbow Surgeons (ASES), Simple Shoulder Test (SST), and patient satisfaction scores were collected.

Surgical details

The revision surgical procedure was performed through the standard deltopectoral approach in all patients, with division of the subscapularis during dissection. Every stem in this cohort was modular, and the humeral head was removed. In all cases, circumferential exposure of the proximal humerus was performed to develop the interface between the proximal stem and the cement mantle. Visualization of the fins of the implant was required prior to extraction. A carbide punch was then placed under the proximal-medial portion of the stem. In cases in which the stem was collared, this was used for implant extraction. If no collar was present, a high-speed burr was used to create a ledge allowing for a direct axial force that would allow removal of the stem. After stem removal, the remaining cement mantle was evaluated regarding the stability of the cement-bone interface, as well as the presence of infection. Preoperatively, all patients underwent laboratory analysis to monitor for elevated levels of inflammatory markers, including a complete blood count, erythrocyte sedimentation rate, and C-reactive protein level. Multiple tissue samples were obtained intraoperatively at the time of reconstruction to assess for infection, with frozen-section analysis and culture in all patients. Patients in whom frozen-section microscopy revealed greater than 5 polymorphonuclear

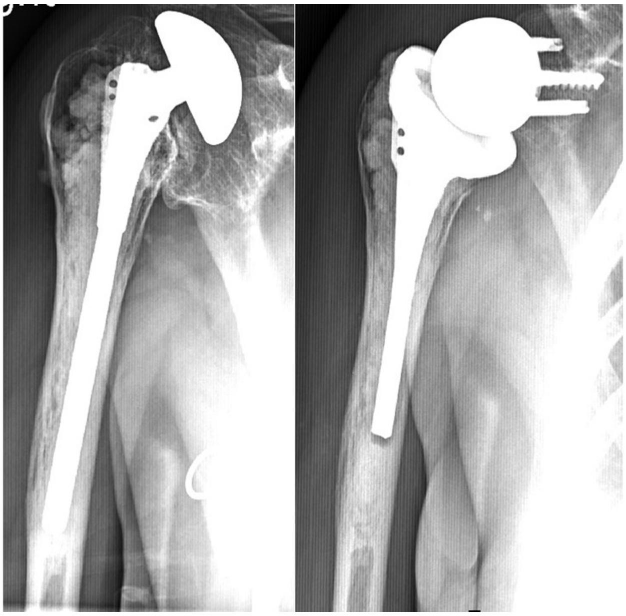

Figure 1 Preoperative and postoperative radiographs of a patient in group 2 (no loosening) who underwent revision of a previously implanted cemented humeral component to a reverse prosthesis by the cement-within-cement technique.

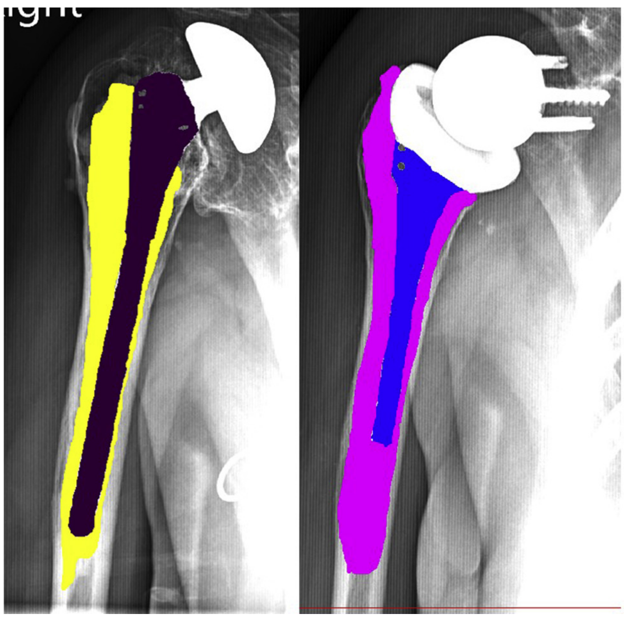

Figure 2 Preoperative and postoperative radiographs of the patient shown in Figure 1 with quantified areas of stem and cement mantle. *Yellow*, preoperative area of cement; *Purple*, preoperative area of stem; *Pink*, postoperative area of cement; *Blue*, postoperative area of stem.

cells per high-power field, those with prior infection, and those with positive postoperative culture results were managed with an intravenous antibiotic regimen by an infectious disease specialist postoperatively. A diaphyseal intramedullary reamer was used to roughen the previous mantle and widen the intramedullary mantle. The prepared mantle was then judiciously cleaned and dried.

The quantity of bone loss was assessed by measuring the gap between the remaining native humeral bone distally along the medial cortex and the inferomedial portion of the polyethylene trial in the humeral component. If the bone loss was deemed extensive enough (33 of 98 patients) to compromise the stability of the revision prosthetic stem, then an allograft-prosthetic composite (APC) was chosen to provide enhanced stability of the construct.

Postoperative care

All patients were placed in a sling for 2 weeks until the first clinical follow-up visit. The sutures were removed at that time if the wound was healed, and the patient was permitted to discontinue sling use. Pendulum exercises were performed until 6 weeks postoperatively, at which point activity was gradually progressed with passive range-of-motion exercises in formal physical therapy. Patients progressed to full activity at 3 months postoperatively.

Statistical analysis

Statistical analysis was performed with the SPSS statistical package (version 24; IBM, Armonk, NY, USA). For radiographic analysis, intraclass correlation coefficient estimates and their 95% confidence intervals (CIs) were calculated using an absolute-agreement, 2-way mixed-effects model. Averages (medians) and standard deviations were reported for every continuous variable studied. The Wilcoxon signed rank test or paired-samples t test was used for continuous variables when appropriate. Percentages were reported for all categorical variables, and the Fisher exact test was used to evaluate associations. Statistical significance was set at $P < .05$.

Results

Statistical analysis indicated excellent reliability of the radiographic method of cement mantle and stem area estimation (intraclass correlation, 0.948 [95% CI, 0.905-0.982]; interclass correlation, 0.997 [95% CI, 0.995-1.000]). The average area of preoperative and postoperative cement in the whole study population measured 8730 ± 7405 mm^2 and 12819 ± 12069 mm^2, respectively. The calculated preoperative-to-postoperative difference in the area of cement was statistically significant ($P = .001$), with an increase of 4089 ± 12253 mm^2. The average area of preoperative stem was 15260 ± 13983 mm^2, and the average area of postoperative stem was 8006 ± 5964 mm^2. The preoperative-to-postoperative difference in the average area of stem was calculated to be a statistically significant decrease of 7254 ± 14966 mm^2 ($P < .0001$). The average filling ratio measured 0.64 ± 0.15 preoperatively and 0.41 ± 0.08 postoperatively. The calculated average preoperative-to-postoperative difference in the filling ratio was a statistically significant decrease of 0.24 ± 0.16 ($P < .0001$).

In group 1 (loosening), the average area of preoperative cement measured 8521 ± 4355 mm^2 and the average area of postoperative cement was 9332 ± 3135 mm^2 (Table II). The

Table II Preoperative and postoperative measurements for total area of cement, total area of stem, and filling ratio

	Group 1 (loosening)				Group 2 (no loosening)			
	Preoperative	Postoperative	*P* value	Δ	Preoperative	Postoperative	*P* value	Δ
Total area of cement, mm^2	8521 ± 4355	9332 ± 3135	.484	811 ± 4014	8748 ± 7633	13129 ± 12522	<.0001	4380 ± 12701
Total area of stem, mm^2	12353 ± 8262	6102 ± 1261	.025	−6251 ± 8861	15519 ± 14384	8175 ± 6188	<.0001	−7343 ± 15423
Filling ratio	0.59 ± 0.12	0.41 ± 0.10	.017	−0.18 ± 0.11	0.65 ± 0.15	0.41 ± 0.08	<.0001	−0.24 ± 0.16

Δ, preoperative-to-postoperative operative difference.

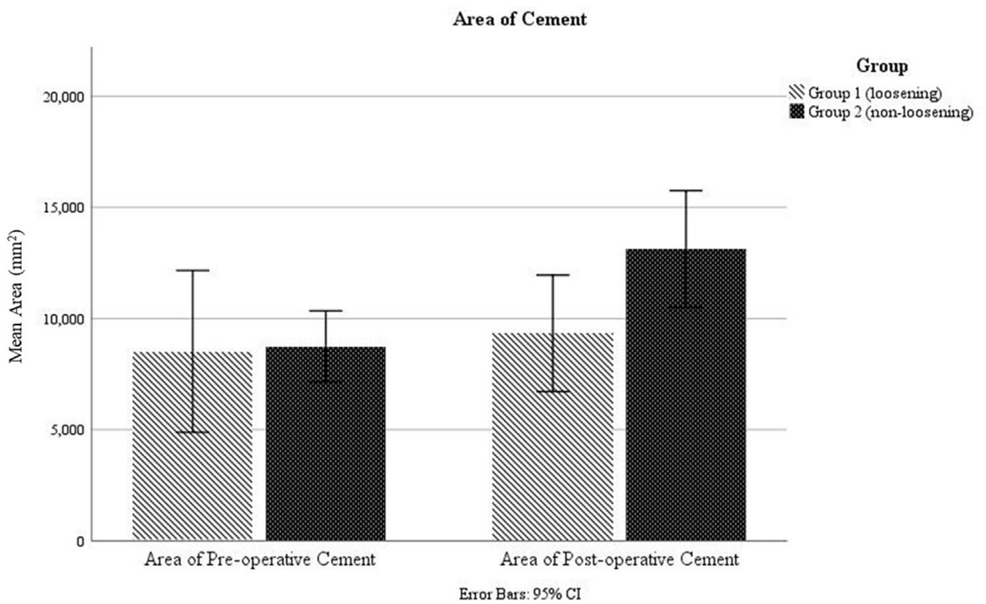

Figure 3 Preoperative and postoperative area of cement mantle (in square millimeters) in groups 1 and 2. *CI*, confidence interval.

calculated preoperative-to-postoperative difference in the area of cement was not statistically significant (P = .484), with only 811 mm^2 of added cement (Fig. 3). In group 2 (no loosening), the average area of preoperative cement measured 8748 ± 7633 mm^2 and the average area of postoperative cement was 13129 ± 12522 mm^2 (Table II). The calculated difference between preoperative and postoperative cement represented a significant increase (P < .0001), with 4380 ± 12701 mm^2 of added cement (Fig. 3).

The preoperative measured area of stem was 12353 ± 8262 mm^2 and the postoperative area of stem was 6102 ± 1261 mm^2 in group 1 (loosening) (Table II). This represented a significant decrease in the preoperative-to-postoperative stem area of 6251 mm^2 (P = .025; Fig. 4). In group 2 (no loosening), the preoperative area of stem measured 15519 ± 14384 mm^2 and the postoperative stem area was 8175 ± 6188 mm^2 (Table II). Again, the difference between the preoperative and postoperative stem area was significant (P < .0001), with a decrease of 7343 mm^2 (Fig. 4).

The preoperative and postoperative filling ratios in group 1 (loosening) were 0.59 ± 0.12 and 0.41 ± 0.10, respectively (Table II). The difference in the group 1 (loosening) filling ratio was statistically significant (P = .017), with a decrease of 0.18 ± 0.11 (Fig. 5). The preoperative and postoperative filling ratios in group 2 (no loosening) were 0.65 ± 0.15 and 0.41 ± 0.08, respectively (Table II). The difference in the filling ratio in group 2 was statistically significant (P < .0001), with a decrease of 0.24 ± 0.16 (Fig. 5).

Implant survival and reoperations

In patients in group 1 (loosening), signs of humeral loosening developed, on average, after 3.9 years (range, 0.6-8.9 years) of follow-up. Group 1 (loosening) showed grade 0 proximal humeral bone loss in 1 of 8 cases (12.5%), grade 1 in 2 of 8 cases (25%), grade 2 in 1 of 8 cases (12.5%), and grade 3 in 4 of 8 cases (50%). In contrast, in group 2 (no loosening), we found grade 0 proximal humeral bone loss

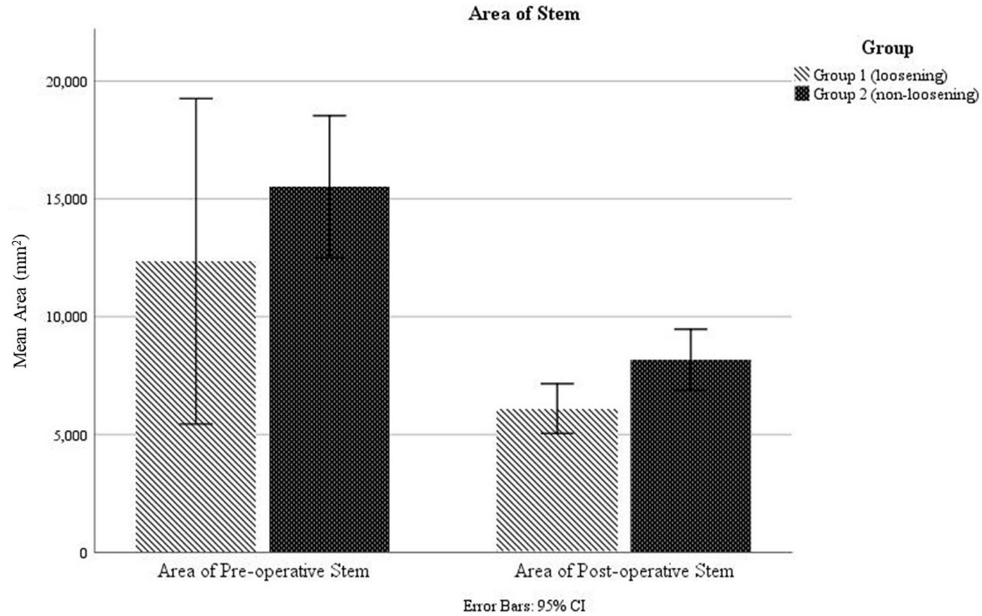

Figure 4 Preoperative and postoperative area of stem (in square millimeters) in groups 1 and 2. *CI*, confidence interval.

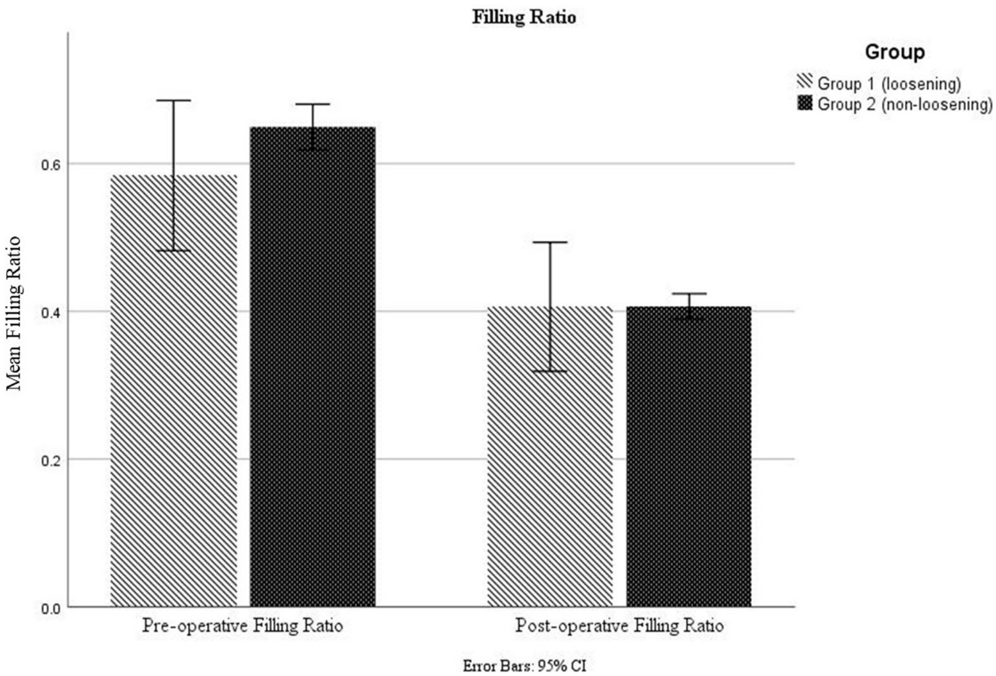

Figure 5 Preoperative and postoperative filling ratios in groups 1 and 2. *CI*, confidence interval.

in 19 of 90 cases (21%), grade 1 in 19 of 90 cases (21%), grade 2 in 34 of 90 cases (38%), and grade 3 in 18 of 90 cases (20%).

In group 1 (loosening), 5 of 8 patients (63%) had an APC used in the revision. On the other hand, in group 2 (no loosening), only 28 of 90 shoulders (31%) required use of an APC in the revision ($P = .1144$).

A second revision surgical procedure was performed in 12 of 98 patients (12%, 5 from group 1 and 7 from group 2) who underwent cement-within-cement humeral component revision ($P = .0005$). The causes of revision included dissociation of the glenosphere (n = 3), infection (n = 3), instability (n = 2), humeral loosening (n = 2), periprosthetic fracture (n = 1), and a broken baseplate (n = 1).

Table III Preoperative and postoperative functional assessments and preoperative-to-postoperative operative differences (available in 57 patients)

	Preoperative	Postoperative	Δ	*P* value
ASES score	35 ± 17	58 ± 19	22 ± 22	<.0001
SST score	2 ± 2	5 ± 4	3 ± 4	<.0001
Forward flexion, °	57 ± 33	104 ± 48	47 ± 54	<.0001
Abduction, °	49 ± 26	96 ± 39	46 ± 42	<.0001
Internal rotation*	2 ± 2	3 ± 2	1 ± 3	.001
External rotation, °	17 ± 20	29 ± 29	12 ± 38	.019

Δ, preoperative-to-postoperative operative difference; *ASES*, American Shoulder and Elbow Surgeons; *SST*, Simple Shoulder Test.
* Internal rotation is reported as a numerical value from 0-8 for the highest point the patient is able to reach behind the back: ipsilateral hip (0), ipsilateral back pocket (1), contralateral back pocket (2), S1 or L5 (3), T11-L1 (4), T7-T10 (5), T4-T6 (6), T2-T3 (7), and C8-T1 (8).

The average time to revision surgery was 3.0 years (range, 0.75-9.8 years).

Clinical outcomes

In our cohort, all outcome measures improved, including the ASES score (mean change, +22 ± 22; $P < .0001$), SST score (mean change, +3 ± 4; $P < .0001$), forward flexion (mean change, +47° ± 54°; $P < .0001$), shoulder abduction (mean change, +46° ± 42°; $P < .0001$), shoulder internal rotation (mean change, +1 ± 3; $P = .001$), and shoulder external rotation (mean change, +12° ± 38°; $P = .019$) at final follow-up (Table III). Furthermore, these patients reported high rates of overall satisfaction (7.4 ± 2.2 of 10).

Discussion

In the setting of a previously implanted cemented humeral component, revision RSA poses many challenges including component and cement removal, preservation of proximal humeral bone stock, and establishment of a stable foundation for the revision humeral stem.[5,7,8,15,16,30-33,35,36] Wagner et al[33] reported on outcomes in the setting of the cement-within-cement technique in revision RSA. They suggested that, when faced with the task of preserving humeral bone stock and stabilizing the revision humeral stem, the cement-within-cement technique is a critical consideration. The purpose of our study was to determine whether aspects of surgical technique could optimize humeral component stability. We hypothesized that a greater increase in the preoperative-to-postoperative amount of cement coupled with preoperative-to-postoperative stem downsizing would decrease the incidence of humeral loosening.

In our cohort, radiographic loosening went on to develop in only 8 of 98 patients (8%). On average, this group of patients had a preoperative area of cement of 8521 mm^2 and a postoperative area of cement of 9332 mm^2. In comparison, 90 of the 98 patients (92%) who did not show loosening had, on average, 8748 mm^2 of preoperative cement and 13129 mm^2 of postoperative cement. There was a statistically significant increase of 4380 mm^2 of added cement in group 2 ($P < .0001$) but an increase of only 811 mm^2 in group 1 ($P = .484$). The group of patients without loosening received 5 times more cement on average than the group with loosening.

In addition, there was a statistically significant reduction in total area of preoperative-to-postoperative stem size of 6251 mm^2 ($P = .025$) in the group with loosening. However, a greater reduction of 7343 mm^2 ($P < .0001$) was found in the group without loosening. Thus, the group without loosening received a stem that was nearly 1.2 times smaller than that in the group with loosening. Furthermore, the preoperative-to-postoperative difference in the filling ratio (ie, area of the stem to combined areas of cement mantle and humeral stem) was 0.18 in the group with loosening and 0.24 in the group without loosening. These findings suggest that to achieve an adequate cement mantle with interdigitation of the prior cement and revision implant, it is preferred to use a smaller humeral stem than the previously implanted component. In addition, incorporating measures to maximize the cement volume used during reimplantation, such as reaming the retained intramedullary cement mantle to allow for a greater volume of new cement, may be considered. Implementation of these efforts may lessen the chance of humeral stem loosening, thus reducing the need for additional revision surgery.

Wagner et al[33] demonstrated a significant improvement in clinical outcome scores, with an average postoperative ASES score of 61, SST score of 5, and shoulder abduction of 108°. Similarly, our average postoperative ASES score was 58, SST score was 5, and abduction was 96°. Furthermore, both studies found a rate of humeral loosening of 8%.

Despite the infrequency of this procedure, our study features the largest series of revision RSA using the cement-within-cement technique in the current literature. However, this study is not without limitations. First, the retrospective design with a single surgeon and limited patient population hinders our ability to examine confounding variables associated with our results. For example, we found that group 1 had a higher percentage of grade 3 bone loss and APC use than group 2, recognizing that these variables also play an integral role in the stability of the construct. However, we cannot know for certain the importance of each of the defined features owing to the interplay among all variables in vivo and the small numbers in our cohort analysis. Another limitation of this study is the use of radiographic area as a surrogate for volume. We consistently used anteroposterior films for modeling and analysis, but we were unable to account for the slight variation in rotation and angulation. However, we attempted to evaluate a clinical tool that could be implemented by and add value for arthroplasty surgeons.

Conclusion

Use of the cement-within-cement technique for fixation of the humeral component in revision RSA is effective in improving functional outcome scores and shoulder range of motion. Furthermore, these findings suggest that efforts should be taken to maximize the added cement volume during reimplantation, including adequately reaming the retained intramedullary cement mantle and implanting a smaller humeral stem than the previous component. Application of these surgical techniques may lessen the chance of humeral stem loosening requiring additional revision.

Disclaimer

Mark A. Mighell receives consulting fees and honoraria for educational services from DJO Surgical, Stryker, and DePuy Synthes and receives royalties from DJO Surgical and NewClip Technics.

Mark A. Frankle receives royalties and consulting fees from DJO Surgical.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Abdel MP, Hattrup SJ, Sperling JW, Cofield RH, Kreofsky CR, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J 2013;95-B:668-72. https://doi.org/10.1302/0301-620X.95B5.30964
2. Ballas R, Béguin L. Results of a stemless reverse shoulder prosthesis at more than 58 months mean without loosening. J Shoulder Elbow Surg 2013;22:e1-6. https://doi.org/10.1016/j.jse.2012.12.005
3. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJ. Reverse shoulder arthroplasty as salvage for failed prior arthroplasty in patients 65 years of age or younger. J Shoulder Elbow Surg 2014;23:1036-42. https://doi.org/10.1016/j.jse.2014.02.019
4. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res 2016;102(Suppl):S33-43. https://doi.org/10.1016/j.otsr.2015.06.031
5. Boileau P, Melis B, Duperron D, Moineau G, Rumian AP, Han Y. Revision surgery of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:1359-70. https://doi.org/10.1016/j.jse.2013.02.004
6. Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of a reverse shoulder prosthesis-allograft composite. J Bone Joint Surg Am 2009;91:119-27. https://doi.org/10.2106/JBJS.H.00094
7. Cil A, Veillette CJ, Sanchez-Sotelo J, Sperling JW, Schleck C, Cofield RH. Revision of the humeral component for aseptic loosening in arthroplasty of the shoulder. J Bone Joint Surg Br 2009;91:75-81. https://doi.org/10.1302/0301-620X.91B1.21094
8. Cil A, Veillette CJ, Sanchez-Sotelo J, Sperling JW, Schleck CD, Cofield RH. Survivorship of the humeral component in shoulder arthroplasty. J Shoulder Elbow Surg 2010;19:143-50. https://doi.org/10.1016/j.jse.2009.04.011
9. Crosby LA, Wright TW, Zuckerman JD. Revision total shoulder arthroplasty without humeral component removal. A preliminary report on the role of a platform humeral component. Bull Hosp Jt Dis (2013) 2015;73(Suppl 1):S136-9.
10. Deutsch A, Abboud JA, Kelly J, Mody M, Norris T, Ramsey ML, et al. Clinical results of revision shoulder arthroplasty for glenoid component loosening. J Shoulder Elbow Surg 2007;16:706-16. https://doi.org/10.1016/j.jse.2007.01.007
11. Dezfuli B, King JJ, Farmer KW, Struk AM, Wright TW. Outcomes of reverse total shoulder arthroplasty as primary versus revision procedure for proximal humerus fractures. J Shoulder Elbow Surg 2016;25:1133-7. https://doi.org/10.1016/j.jse.2015.12.002
12. Duncan WW, Hubble MJ, Howell JR, Whitehouse SL, Timperley AJ, Gie GA. Revision of the cemented femoral stem using a cement-in-cement technique: a five- to 15-year review. J Bone Joint Surg Br 2009;91:577-82. https://doi.org/10.1302/0301-620X.91B5.21621
13. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 1979:17-27.
14. Holt G, Hook S, Hubble M. Revision total hip arthroplasty: the femoral side using cemented implants. Int Orthop 2011;35:267-73. https://doi.org/10.1007/s00264-010-1167-5
15. Johnston PS, Creighton RA, Romeo AA. Humeral component revision arthroplasty: outcomes of a split osteotomy technique. J Shoulder Elbow Surg 2012;21:502-6. https://doi.org/10.1016/j.jse.2011.02.001
16. Kelly JD, Zhao JX, Hobgood ER, Norris TR. Clinical results of revision shoulder arthroplasty using the reverse prosthesis. J Shoulder Elbow Surg 2012;21:1516-25. https://doi.org/10.1016/j.jse.2011.11.021
17. Klein SM, Dunning P, Mulieri P, Pupello D, Downes K, Frankle MA. Effects of acquired glenoid bone defects on surgical technique and clinical outcomes in reverse shoulder arthroplasty. J Bone Joint Surg Am 2010;92:1144-54. https://doi.org/10.2106/JBJS.I.00778
18. Levy JC, Virani N, Pupello D, Frankle M. Use of the reverse shoulder prosthesis for the treatment of failed hemiarthroplasty in patients with glenohumeral arthritis and rotator cuff deficiency. J Bone Joint Surg Br 2007;89:189-95. https://doi.org/10.1302/0301-620X.89B2.18161
19. Mandziak DG, Howie DW, Neale SD, McGee MA. Cement-within-cement stem exchange using the collarless polished double-taper stem. J Arthroplasty 2007;22:1000-6. https://doi.org/10.1016/j.arth.2007.06.001
20. Melis B, Bonnevialle N, Neyton L, Levigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder

arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Shoulder Elbow Surg 2012;21:342-9. https://doi.org/10.1016/j.jse.2011.05.021

21. Morley JR, Blake SM, Hubble MJ, Timperley AJ, Gie GA, Howell JR. Preservation of the original femoral cement mantle during the management of infected cemented total hip replacement by two-stage revision. J Bone Joint Surg Br 2012;94:322-7. https://doi.org/10.1302/0301-620X.94B3.28256
22. Mounsey EJ, Williams DH, Howell JR, Hubble MJ. Revision of hemiarthroplasty to total hip arthroplasty using the cement-in-cement technique. Bone Joint J 2015;97-B:1623-7. https://doi.org/10.1302/0301-620X.97B12.35814
23. Ortmaier R, Resch H, Matis N, Blocher M, Auffarth A, Mayer M, et al. Reverse shoulder arthroplasty in revision of failed shoulder arthroplasty—outcome and follow-up. Int Orthop 2013;37:67-75. https://doi.org/10.1007/s00264-012-1742-z
24. Palsis JA, Simpson KN, Matthews JH, Traven S, Eichinger JK, Friedman RJ. Current trends in the use of shoulder arthroplasty in the United States. Orthopedics 2018;41:e416-23. https://doi.org/10.3928/01477447-20180409-05
25. Patel DN, Young B, Onyekwelu I, Zuckerman JD, Kwon YW. Reverse total shoulder arthroplasty for failed shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:1478-83. https://doi.org/10.1016/j.jse.2011.11.004
26. Randelli P, Randelli F, Compagnoni R, Cabitza P, Ragone V, Pulici L, et al. Revision reverse shoulder arthroplasty in failed shoulder arthroplasties for rotator cuff deficiency. Joints 2015;3:31-7.
27. Saltzman BM, Chalmers PN, Gupta AK, Romeo AA, Nicholson GP. Complication rates comparing primary with revision reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1647-54. https://doi.org/10.1016/j.jse.2014.04.015
28. Sanchez-Sotelo J, O'Driscoll SW, Torchia ME, Cofield RH, Rowland CM. Radiographic assessment of cemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg 2001;10:526-31.
29. Stefanovich-Lawbuary NS, Parry MC, Whitehouse MR, Blom AW. Cement in cement revision of the femoral component using a collarless triple taper: a midterm clinical and radiographic assessment. J Arthroplasty 2014;29:2002-6. https://doi.org/10.1016/j.arth.2014.05.002
30. Stephens SP, Paisley KC, Giveans MR, Wirth MA. The effect of proximal humeral bone loss on revision reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1519-26. https://doi.org/10.1016/j.jse.2015.02.020
31. Valenti P, Kilinc AS, Sauzières P, Katz D. Results of 30 reverse shoulder prostheses for revision of failed hemi- or total shoulder arthroplasty. Eur J Orthop Surg Traumatol 2014;24:1375-82. https://doi.org/10.1007/s00590-013-1332-9
32. Wagner ER, Houdek MT, Elhassan BT, Sanchez-Sotelo J, Cofield RH, Sperling JW. What are risk factors for intraoperative humerus fractures during revision reverse shoulder arthroplasty and do they influence outcomes? Clin Orthop Relat Res 2015;473:3228-34. https://doi.org/10.1007/s11999-015-4448-x
33. Wagner ER, Houdek MT, Hernandez NM, Cofield RH, Sánchez-Sotelo J, Sperling JW. Cement-within-cement technique in revision reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1448-53. https://doi.org/10.1016/j.jse.2017.01.013
34. Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:514-22. https://doi.org/10.1016/j.jse.2011.03.006
35. Werner BS, Boehm D, Gohlke F. Revision to reverse shoulder arthroplasty with retention of the humeral component. Acta Orthop 2013;84:473-8. https://doi.org/10.3109/17453674.2013.842433
36. Wright TW. Revision of humeral components in shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):77-81.