



# Radiographic outcomes of impaction-grafted standard-length humeral components in total shoulder and ream-and-run arthroplasty: is stress shielding an issue?

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**Background:** The purpose of this study was to evaluate humeral stress shielding in shoulder arthroplasties performed with a smooth, standard-length humeral stem fixed with impaction autografting.

**Methods:** Two-year outcomes were evaluated for 48 ream-and-run arthroplasties and 78 total shoulder arthroplasties (TSAs) performed at a single institution. Postoperative radiographs were analyzed for adaptive changes, calcar osteolysis, and component shift or subsidence. Radiographic outcomes were analyzed for associations with patient demographic characteristics, humeral stem filling ratios, and glenoid loosening; clinical outcomes were assessed using the Simple Shoulder Test.

**Results:** At 2 years after surgery, the ream-and-run procedures showed partial calcar osteolysis in 9 cases (19%). The TSAs showed partial calcar osteolysis in 19 cases (24%) and complete calcar osteolysis in 2 (3%). Humeral component subsidence or component shift was observed in 3 ream-and-run procedures (6%) and in 8 TSAs (10%). These radiographic findings were not significantly associated with patient demographic characteristics, canal-filling ratios, or clinical outcomes.

**Conclusion:** When inserted with impaction autografting, a smooth, standard-length humeral stem offers a secure bone-preserving approach for humeral component fixation in shoulder arthroplasty. These results with a conventional prosthesis can serve as a basis for comparison for new component designs and fixation methods.

**Level of evidence:** Level IV; Case Series; Treatment Study

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**Keywords:** Total shoulder arthroplasty; ream and run; humeral loosening; stress shielding; press fit; bone adaptations; impaction grafting

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Fixation of the humeral component to the humerus is an essential element of prosthetic shoulder arthroplasty. Conventionally, a standard-length (typically 130-155 mm) humeral component is fixed to the bone by cement or diaphyseal press fitting.<sup>6,16</sup> Although the reported rate of humeral component loosening is low,<sup>1,22</sup> surgical revision of the humeral component is not uncommonly required to address problems such as glenoid loosening, infection, and rotator cuff failure.<sup>28,35</sup> Removal of cemented or diaphyseal press-fit stems can be difficult and can lead to intraoperative fracture and humeral bone deficiency.<sup>7,17</sup> In addition, diaphyseal press-fit and ingrowth stems can lead to proximal stress shielding, compromising bone quality.<sup>8,10,15,16,27-29</sup> This effect appears to be magnified if the prosthetic humeral stem occupies a high percentage of the humeral canal, that is, if there is a high canal-filling ratio.<sup>10,15,27,33,40</sup> These reports have led surgeons to explore new humeral prosthesis implants and fixation methods designed to achieve secure fixation while preserving humeral bone stock and facilitating revision, should it become necessary.<sup>3,5,8,9,11,26,31,42</sup>

An alternative approach to preserving bone stock and avoiding stress shielding is to insert a conventional, standard-length, smooth humeral stem that does not completely occupy the humeral canal and to use a humeral head autograft<sup>13,20</sup> to fill the voids in the irregularly shaped canal.<sup>2,19,30</sup> In this technique, smaller-diameter stems can be used because the autograft removes the need for a tight fit of the prosthesis against the endosteal surface of the cortex. Previous studies have demonstrated a low rate of stem loosening with this technique despite the absence of porous coating on the stem.<sup>20,44</sup> However, the amount of stress shielding with this technique has not been previously evaluated.

The purpose of this study was to evaluate the 2-year radiographic and clinical outcomes of shoulder arthroplasty performed with a conventional, standard-length, smooth humeral stem inserted with impaction autografting. The hypothesis was that this approach would enable the secure fixation of stems with relatively small filling ratios and yield low rates of radiographic stress shielding and stem loosening.

## Materials and methods

We performed a retrospective review of the ream-and-run arthroplasties<sup>12,36,38</sup> and anatomic total shoulder arthroplasties (TSAs) that were performed by 1 of 2 shoulder specialist surgeons at a single academic institution and were entered into a longitudinally maintained institutional database between November 2011 and March 2016. The inclusion criteria included (1) a primary ream-and-run arthroplasty or TSA performed for glenohumeral arthritis using a conventional, standard-length, smooth, uncoated humeral stem (Global Advantage; DePuy Synthes; Warsaw, IN, USA) inserted with impaction autografting; (2) a complete set of radiographs to adequately evaluate stress shielding and stem position, consisting of standardized anteroposterior (AP) and axillary radiographs before surgery, 6 weeks after surgery, and 2

years after surgery; and (3) preoperative and 2-year postoperative Simple Shoulder Test (SST) scores. In that this was a study of radiographic changes at 2 years after primary arthroplasty, patients who underwent any repeated closed or open shoulder procedure during the 2-year postoperative study period were excluded from the primary analysis.

During the study period, 345 patients underwent a primary TSA or ream-and-run arthroplasty (195 TSAs and 150 ream-and-run procedures). Of these patients, 219 did not meet the study criteria for analysis: 49 patients lacked either preoperative or 2-year postoperative SST scores, 21 patients underwent a repeated procedure prior to the minimum follow-up, and 149 shoulders lacked either 6-week or 2-year postoperative radiographic views adequate for radiographic analysis. Thus, the final study cohort included 126 patients, consisting of 48 ream-and-run procedures and 78 TSAs, evaluated at a mean follow-up of  $25 \pm 2$  months. The mean age was  $66 \pm 10$  years (range, 35-87 years), 68% of patients were men, and 54% of cases involved the dominant arm.

## Surgical technique

All shoulder arthroplasties were performed using a consistent technique.<sup>23,24</sup> The choice between ream-and-run arthroplasty and TSA was made after a detailed discussion with each patient regarding the risks and alternatives of each approach respecting his or her desired level of activity. Type B glenoids were present in 73% of the ream-and-run arthroplasties and 58% of the TSAs. A deltopectoral approach was used to gain access to the glenohumeral joint. The subscapularis was detached with a peel technique. The humeral canal was opened with a 6-mm-diameter reamer; progressively larger-diameter reamers were used until light endosteal contact was obtained in the diaphysis. A fixed-angle  $135^\circ$  cut of the humeral head was performed in  $30^\circ$  of retroversion, followed by removal of osteophytes. Prior to placement of the final component, cancellous autograft harvested from the humeral head was placed in the humeral canal and pressed into place using a humeral impactor with the same stem geometry as the implant. Autograft was progressively inserted until the impactor fit tightly within the humerus. The final uncoated, smooth, stemmed, fixed-angle humeral component with the desired head geometry was then placed in the prepared canal. The subscapularis was securely reattached to the lesser tuberosity with 6 transosseous nonabsorbable sutures placed prior to component insertion.

For the TSAs, a cemented, pegged, all-polyethylene glenoid with a central fluted peg component (Anchor Peg; DePuy Synthes) was inserted with cementing of the peripheral pegs. In the case of the ream-and-run procedure, the glenoid was reamed to a diameter of curvature 2 mm larger than that of the humeral head prosthesis.

The postoperative program was the same for both types of arthroplasty. Active-assisted flexion exercises were initiated on the evening of surgery. Progressive strengthening was started at 6 weeks. At 3 months after surgery, patients progressively resumed their normal activities.

## Clinical evaluation

Functional outcome was assessed with the SST preoperatively and at final follow-up.<sup>14</sup> The magnitude of change, as well as the percentage of maximum possible improvement (MPI), was calculated.<sup>12,25,36-38</sup>

## Radiographic evaluation

Deidentified, standardized Grashey (true glenohumeral AP view) and true axillary radiographs<sup>21</sup> were obtained preoperatively, at 6 weeks after surgery, and at 2-year follow-up<sup>40</sup> (Fig. 1). The radiology technologists attempted to standardize the position and rotation of the arm, but this was sometimes difficult because of glenohumeral arthritis or the body habitus. These images were reviewed in DICOM (Digital Imaging and Communications in Medicine) format using OsiriX Lite (Pixmeo, Bernex, Switzerland) by an independent shoulder surgeon examiner (P.J.D.) from a different practice who was experienced in the radiographic measurement of adaptive changes but who was not involved in the care of the patients, who uses a different implant system, and who was blinded to the clinical outcomes.

Radiographs were analyzed according to previously published guidelines.<sup>10</sup> On the 6-week postoperative radiographs, the filling ratios (the width of the humeral component divided by the width of the bone) were measured at the diaphysis (diaphyseal filling ratio [FRdia]) at the midpoint of the humeral stem and at the metaphysis (metaphyseal filling ratio [FRmet]) at the level of the inferior head, as described by Schnetzke et al<sup>33</sup> (Fig. 1, B). The filling ratio was recorded on both AP and axillary views separately and then averaged for an overall filling ratio at both the level of the metaphysis and the level of the diaphysis.

Radiographic changes were recorded by comparing the 6-week postoperative and 2-year postoperative radiographs. Radiographic changes were evaluated in 10 humeral zones (5 AP and 5 axillary lateral zones) (Fig. 2).<sup>10</sup> Each zone was evaluated for the presence or absence of cortical thinning or osteopenia graded as yes or no. A total bony adaptive change score for all 10 zones was then calculated. The radiographic changes from each zone were summed for an overall grading of none (0-1 change), mild (2-3 changes), moderate (4-6 changes), or advanced (>6 changes).<sup>33</sup> These were also collapsed into 2 categories: low adaptive changes (represented by none or mild) or high adaptive changes (represented by moderate or advanced). In addition, radiolucent lines in each zone were recorded to the nearest 0.5 mm. Medial calcar osteolysis was noted as none, partial, or complete.<sup>4</sup> Humeral component subsidence and/or varus or valgus shift between the immediate postoperative and final postoperative radiographs was recorded (Fig. 3). A stem was considered at radiographic risk of loosening if it demonstrated subsidence, showed stem tilting (defined as a change of  $\geq 5^\circ$  in the angulation of the stem), or had 2-mm radiolucent lines in 3 or more zones.<sup>39</sup>

In the TSA group, radiolucent lines around the glenoid component were graded from 0 to 5 based on the Lazarus classification for pegged glenoids.<sup>18</sup> In addition, bone ingrowth around the central peg was graded from 1 to 3, where a score of 3 represented bone ingrowth centrally with increased density, a score of 2 represented bone contact with the central peg without increased density between the central fins, and a score of 1 represented osteolysis around the central fins.<sup>45</sup>

## Statistical analysis

Continuous variables were described by mean and standard deviation (SD), and categorical variables, by count and percentage. Mean preoperative and mean 2-year postoperative SST scores were compared using the paired *t* test. The associations of patient

and shoulder factors with the bony adaptive change score were assessed using Spearman correlation ( $\rho$ ) for continuous factors and using the median, interquartile range (IQR), and Wilcoxon rank sum test for categorical factors. The associations of patient and shoulder factors with shift or subsidence were assessed by logistic regression (via the Firth penalized likelihood approach). The associations of patient, shoulder, and radiographic factors with the 2-year SST and percentage of MPI were assessed using linear regression. The characteristics of the TSA cases and the ream-and-run cases were compared using the unpaired *t* test for continuous variables and  $\chi^2$  test for categorical variables. All calculations were carried out by an experienced statistician using the R program (version 3.5.0; R Foundation for Statistical Computing, Austria, Vienna).  $P < .05$  was used to denote statistical significance.

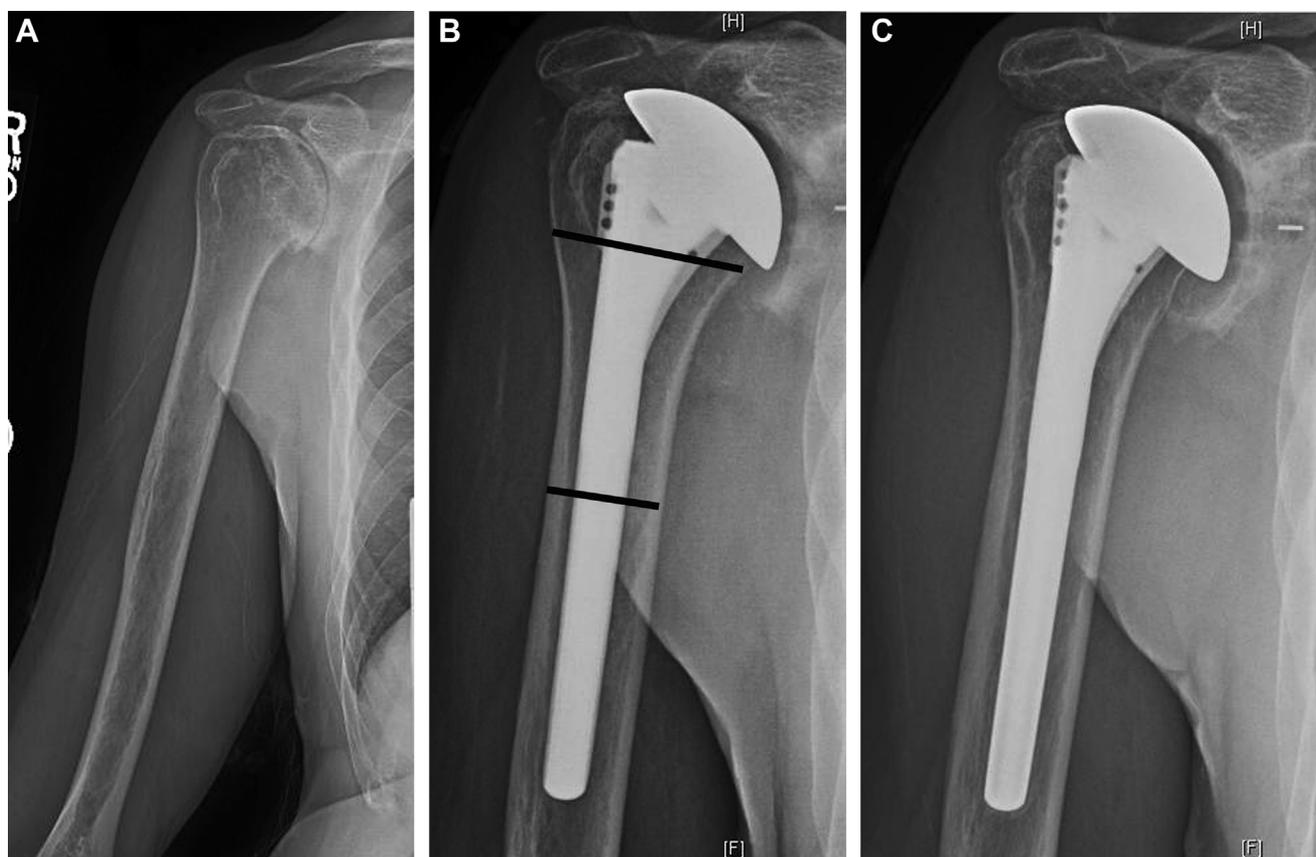
## Results

In the overall cohort, the SST improved from  $3.9 \pm 2.5$  before surgery to  $9.9 \pm 2.4$  postoperatively ( $P < .001$ ) for a mean percentage of MPI ( $\pm$ SD) of  $75.1\% \pm 26.4\%$ . This improvement in the SST easily exceeded the values for the minimal clinically important difference reported by Tashjian et al<sup>41</sup> (2.4), Roy et al<sup>32</sup> (3), and Simovitch et al<sup>34</sup> (1.5). Baseline radiographic characteristics for the immediate postoperative films are summarized in Table I. At final follow-up, the mean bony adaptive change score in the overall cohort was  $1.2 \pm 1.3$ . No radiographic changes occurred in 43% of cases. The adaptive changes were considered low in 92% of cases and high in only 8%. Radiographic findings at final follow-up are summarized in Table II. Shoulder characteristics and radiographic and clinical outcomes of the TSAs and ream-and-run procedures are compared in Table III; the radiographic changes were not significantly different for the 2 procedures.

## Total shoulder arthroplasties

TSAs were performed in 78 patients (mean age  $\pm$  SD,  $68 \pm 9$  years; 41 men [53%]); 58% of these shoulders had type B glenoid pathology (Table III). At 2 years after surgery, 19 shoulders (24%) had partial calcar osteolysis and 2 (3%) had complete calcar osteolysis. Radiographic evidence of humeral component subsidence or shift in position was found in 8 (10%). None of the variables studied, including age, sex, FRmet, and FRdia, were significantly ( $P < .05$ ) associated with osteolysis, shift, or subsidence. No association of total adaptive change score with glenoid status was found based on the Lazarus ( $P = .820$ ) or Wirth ( $P = .618$ ) score. Furthermore, no association of calcar osteolysis with either glenoid score was found ( $P = .555$  for Lazarus score and  $P = .487$  for Wirth score).

The SST scores for these patients improved by an average of  $75\% \pm 26\%$  of the MPI. The percentage of MPI achieved was not significantly correlated with shift in stem position, subsidence, or degree of osteolysis.



**Figure 1** (A) Preoperative anteroposterior radiograph of the right shoulder of a 74-year-old physician with osteoarthritis. (B) Immediate postoperative radiograph showing fixation of a smooth humeral stem with impaction autografting. It should be noted that the prosthetic stem does not fill the humeral canal. The *upper line* shows the location of the measurement of the metaphyseal filling ratio, and the *lower line* shows the location of the measurement of the diaphyseal filling ratio. In each case, the filling ratio is the width of the prosthesis divided by the width of the humerus. (C) Two-year postoperative radiograph showing stable fixation without loss of component position.

### Ream-and-run arthroplasties

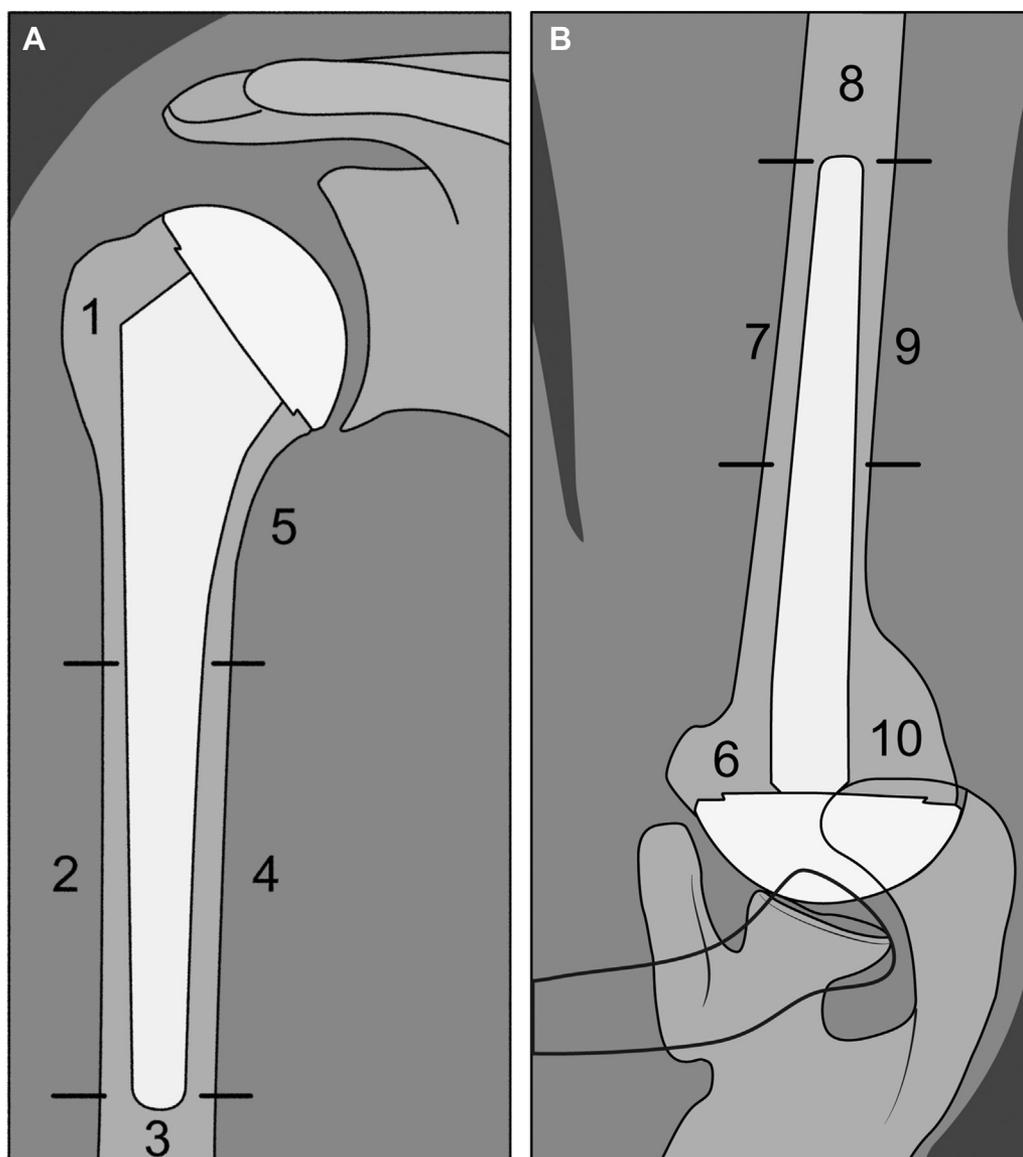
Ream-and-run procedures were performed in 48 patients (mean age  $\pm$  SD,  $62 \pm 10$  years; 45 men [94%]) (Table III). Of these patients, 73% had type B glenoid pathology. At 2 years after surgery, 9 patients (19%) had partial calcar osteolysis and none had complete calcar osteolysis. Radiographic evidence of humeral component subsidence or shift in position was found in 3 (6%). The 3 female patients had a higher bony adaptive change score (median score, 2; IQR, 1.5-2) than the male patients (median score, 1; IQR, 1-1;  $P = .030$ ). Other than the effects of patient sex on bony adaptive change in the ream-and-run procedures, none of the variables studied, including age, sex, FRmet, and FRdia, were significantly ( $P < .05$ ) associated with osteolysis, shift, or subsidence.

The SST scores for these patients improved by an average of  $75\% \pm 27\%$  of the MPI. The percentage of MPI achieved was not significantly correlated with shift in stem position, subsidence, or degree of osteolysis.

### Complications and repeated procedures

No intraoperative complications occurred in the cohort; specifically, no intraoperative fractures occurred on humeral preparation or on humeral component insertion. No patient undergoing impaction grafting sustained a periprosthetic fracture within 2 years of the procedure. None of the TSA patients required revision for glenoid loosening within the 2-year postoperative period.

Among the 345 ream-and-run arthroplasties and TSAs performed during the period of this study, 21 patients underwent 22 revision procedures during the study period. Sixteen patients required closed manipulation for postoperative stiffness, one of whom underwent a second procedure consisting of an open capsular release. One patient underwent downsizing of the humeral head because of stiffness. In 4 patients, stem revision was required prior to 2-year follow-up: 3 had secure stems that were removed because of suspected infection and 1 underwent revision because of loosening. These shoulders undergoing repeated procedures within the study period were not included in



**Figure 2** Zones 1 through 10 for radiographic evaluation of stress shielding with a standard-length stem on anteroposterior (A) and axillary lateral (B) radiographs.

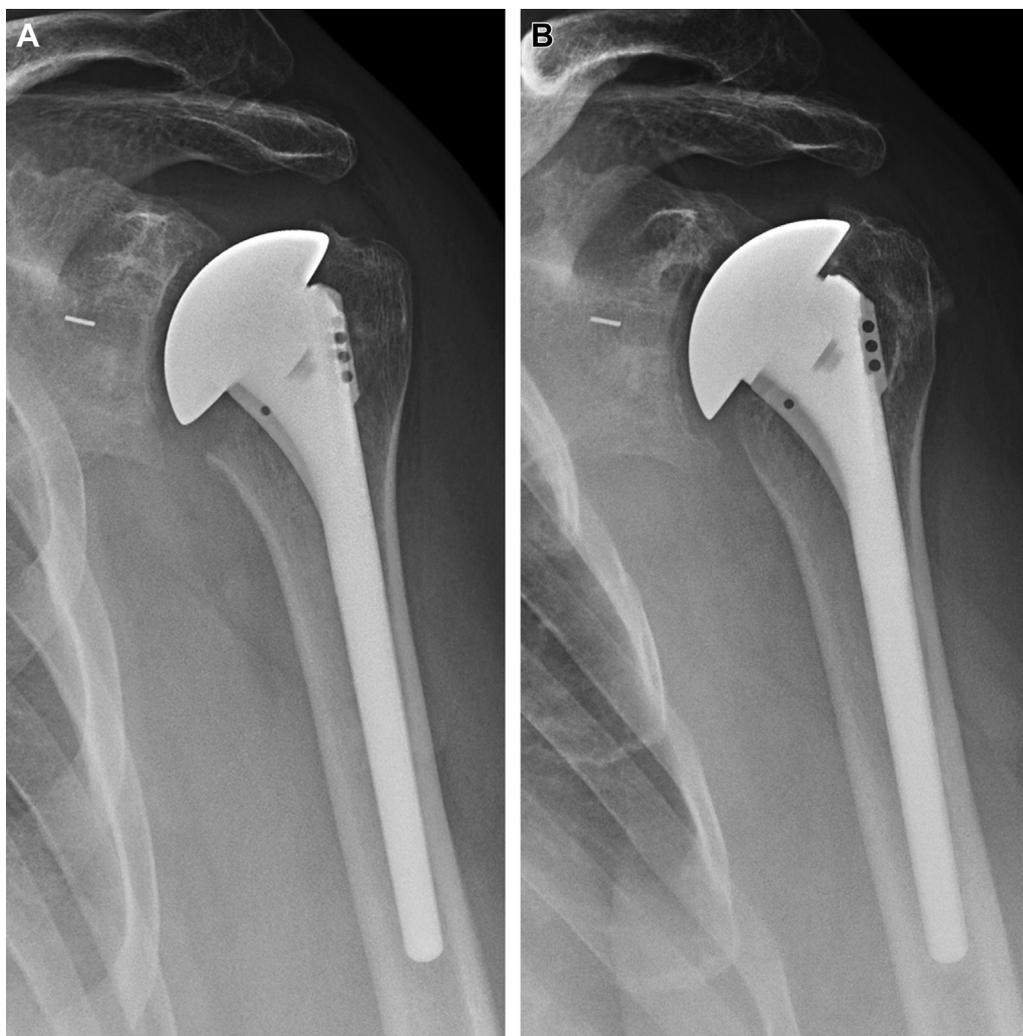
the analysis of 2-year radiographic adaptive changes after primary shoulder arthroplasty.

## Discussion

An independent assessment of the 2-year radiographic and clinical outcomes of a conventional smooth humeral stem inserted with impaction autografting indicates the clinical utility of this bone-preserving approach to humeral component fixation with minimal complications; good clinical outcomes; and low rates of bone loss, component subsidence, and shift in position.

Our findings can be compared with prior reports using different approaches regarding humeral component type and fixation. Verborgt et al<sup>43</sup> reviewed 37 press-fit humeral stems (Neer II [3M, St. Paul, MN, USA]) at a mean of 9.2

years after surgery. Although no revisions occurred, 59% of cases had radiolucencies, 32% had endosteal erosion, 14% had tilting, and 19% were considered at radiographic risk of loosening. In a multicenter retrospective study, Raiss et al<sup>29</sup> analyzed 395 humeral stems at a mean follow-up of 8.2 years. Press-fit fixation was used in 36 hemiarthroplasties and 67 TSAs, whereas the remainder were cemented. Stress shielding was noted in 63% of the press-fit stems overall. In the press-fit TSA group, 42% of cases had osteolysis of the greater tuberosity and 39% had osteolysis of the medial calcar (21% complete and 18% partial). Several studies have demonstrated that a high canal-filling ratio leads to proximal stress shielding. In particular, filling the canal distally leads to diaphyseal fixation that unloads the proximal humerus, manifesting as proximal resorption. Nagels et al<sup>27</sup> reported on 70 humeral



**Figure 3** Anteroposterior radiographs at 6 weeks (A) and 2 years (B) postoperatively showing a small amount of humeral subsidence.

**Table I** Filling ratios for 126 shoulders

	Mean $\pm$ SD (range)
AP	
FRmet	0.39 $\pm$ 0.06 (0.19-0.53)
FRdia	0.44 $\pm$ 0.08 (0.21-0.64)
Axial	
FRmet	0.41 $\pm$ 0.06 (0.30-0.61)
FRdia	0.46 $\pm$ 0.08 (0.26-0.67)
Mean	
FRmet	0.40 $\pm$ 0.05 (0.26-0.55)
FRdia	0.45 $\pm$ 0.1 (0.23-0.67)

SD, standard deviation; FRmet, metaphyseal filling ratio; AP, anteroposterior view; FRdia, diaphyseal filling ratio.

**Table II** Two-year follow-up radiographic findings of 126 shoulders

	Mean $\pm$ SD (range) or n (%)
Lazarus glenoid score	0.6 $\pm$ 1.1 (0.0-4.0)
Wirth glenoid score	2.6 $\pm$ 0.7 (1.0-3.0)
Total bony adaptive change score	1.2 $\pm$ 1.3 (0.0-5.0)
Calcar osteolysis	
No	95 (76.0)
Partial	28 (22.4)
Complete	2 (1.6)
Humeral subsidence or shift	11 (8.8)
Humerus at risk of loosening	12 (9.6)

SD, standard deviation.

stems (64 press fit) at a mean follow-up of 5.3 years and noted that 9% had a reduction in cortical thickness in the proximal-lateral region. They correlated this change with a larger stem size. Spormann et al<sup>40</sup> reported a 17% rate (22

of 132 cases) of full-thickness proximal cortical resorption in TSAs using press-fit stems followed up for a minimum of 5 years. Notably, all patients demonstrated resorption

**Table III** Comparison of shoulders undergoing TSA and those undergoing ream-and-run procedure

	TSA	Ream-and-run procedure	P value
No. of shoulders	78	48	
Age, mean $\pm$ SD, yr	68 $\pm$ 9	62 $\pm$ 10	<.001*
Male patients, n (%)	41 (53)	45 (94)	<.001†
Type B glenoids, n (%)	45 (58)	35 (73)	.085†
Partial calcar osteolysis, n (%)	19 (24)	9 (19)	.462†
Complete calcar osteolysis, n (%)	2 (3)	0 (0)	Indeterminate†
Subsidence or shift, n (%)	8 (10)	3 (6)	.439†
% of MPI for SST, mean $\pm$ SD	75 $\pm$ 26	75 $\pm$ 27	>.999*

TSA, total shoulder arthroplasty; SD, standard deviation; SST, Simple Shoulder Test; MPI, maximum possible improvement.

\* Unpaired *t* test.

†  $\chi^2$  Test.

within 24 months after surgery, indicating that evidence of stress shielding can be detected at the 2-year follow-up performed in our study. Resorption was correlated with a greater degree of canal filling (larger prosthesis size relative to the size of the bone), with the risk of resorption being 2.3 times higher if the humerus-to-prosthesis width was less than 1.4. It should be noted that the filling ratio represents the inverse of this ratio; therefore, this value corresponds to a filling ratio of approximately 0.7. Schnetzke et al<sup>33</sup> evaluated 52 short humeral stems at a minimum of 2 years after surgery and noted medial calcar thinning in 83% of stems and high adaptive changes in 52% of stems. They did not report their overall filling ratio, but they reported that the mean filling ratios were greater in patients with high adaptive changes (FRmet of 0.6 vs. 0.56,  $P = .024$ ; FRdia of 0.66 vs. 0.61,  $P = .019$ ).

In our study, the mean filling ratios were lower than those in these prior studies, with a metaphyseal ratio of only 0.40 and diaphyseal ratio of only 0.45. These low filling ratios may account for the low incidence of adaptive changes and calcar osteolysis seen in the results for all shoulders in this study (Table IV): Only 8% of humeral stems demonstrated “high” adaptive changes, and only 1.6% of cases demonstrated complete calcar osteolysis. These findings lend further support to the concept that high distal canal filling can contribute to proximal stress shielding in shoulder arthroplasty and that impaction bone grafting of smaller-diameter stems can be used to obtain fixation while preserving bone stock and avoiding the negative effects of high distal canal filling. Despite minimal canal filling, the radiographic risk of loosening of the humeral stems in our study was only 9.6%. These radiographic outcomes for all shoulders compare favorably with previously reported studies as well as recent reports of short stems (Table IV).<sup>31</sup> If only the TSAs in our study are considered, the radiographic outcomes—partial calcar osteolysis in 24% of cases, complete calcar osteolysis in 3%, and subsidence or shift in position in 10%—are comparable with those in other reported series as listed in Table IV. In our series, the radiographic and clinical outcomes were not significantly different between the TSAs and ream-and-run arthroplasties (Table III).

There is some controversy regarding the need for porous coating on humeral stems, which may depend on a combination of stem length (short vs. standard) and stem design (ie, collar vs. no collar or fins vs. no fins).<sup>4,8,26,29,31</sup> Our results demonstrated that porous coating is not required for stability when a standard-length, smooth stem is inserted with impaction grafting. In the aforementioned study by Raiss et al,<sup>29</sup> 103 of the humeral stems were placed in an uncemented fashion using a standard-length stem with proximal grit blasting and a lateral fin. No cases of stem shift or subsidence were reported. Conversely, the need for porous coating may vary with short-stemmed humeral components. Casagrande et al<sup>4</sup> reported high rates of loosening with a short finless stem (Ascend; Wright Medical Group, Memphis, TN, USA) with grit blasting. At a mean follow-up of 33 months, of 69 TSAs, 8.2% required removal and an additional 8.7% were considered at radiographic risk of loosening. Subsequently, the stem was modified in the second-generation convertible version (Ascend Flex; Wright Medical Group) to include proximal porous coating. Morwood et al<sup>26</sup> compared the outcomes of the 2 stems in a retrospective study of 68 TSAs reviewed at a mean of 27 months postoperatively. Only 1 of the 34 coated stems subsided (2.9%), whereas 1 of the 34 first-generation stems (2.9%) required removal and an additional 7 (20.6%) were considered at radiographic risk of loosening. Morwood et al concluded that the proximal porous coating was advantageous for a short stem. However, Denard et al<sup>8</sup> compared the outcomes of a short stem (Apex Univers; Arthrex, Naples, FL, USA) vs. a standard-length stem (Univers II; Arthrex) at a minimum follow-up of 2 years and found no differences between the 2 stems with respect to the rate of loosening. Both stems have a collar and grit blasting only.

Our study suggests that grit blasting and porous coating are unnecessary when a standard-length, smooth humeral stem is inserted with impaction autografting. The absence of a bone ingrowth surface can facilitate humeral stem removal, should it become necessary.

The results of this study should be viewed in light of certain limitations. First, the procedures were performed at a high-volume shoulder arthroplasty center and may not be generalizable to other settings. Second, although the cohort

**Table IV** Summary of radiographic changes in current study and in published literature

Study	Cohort	Mean follow-up, mo	FRmet	FRdia	Bone adaptive change score	Low adaptive changes, %	High adaptive changes, %	Partial calcar osteolysis, %	Complete calcar osteolysis, %	Subsidence or shift, %	Revision for loosening, %
Current study	Standard stem	25	0.40	0.45	1.2	92	8	22	1.6	9.6	0
Casagrande et al <sup>4</sup>	Short stem	33	NA	NA	NA	NA	NA	15	2.9	NA	8.2
Denard et al <sup>8</sup>	Short stem	25	NA	NA	2.2	82	18	23	0	5.4	0
	Standard stem	31			2.4	78	22	31	0	1.7	0
Denard et al <sup>9</sup>	Short stem, collarless	35	0.55	0.56	3.9	38	62	64	7	14	0
	Standard stem, collared	25	0.62	0.52	2.5	77	23	29	0	8.6	0
Schnetzke et al <sup>33</sup>	Short stem	32	0.56 for low adaptive changes 0.60 for high adaptive changes	0.61 for low adaptive changes 0.66 for high adaptive changes	NA	48	52	NA	NA	0	0

FRmet, metaphyseal filling ratio; FRdia, diaphyseal filling ratio; NA, not available.

was relatively large, a substantial number of shoulders had to be excluded because of the lack of 6-week and 2-year radiographic views that were sufficiently comparable to determine the adaptive changes; however, it seems unlikely that the exclusion of shoulders with noncomparable radiographic views would have introduced a selection bias. Third, the outcomes were assessed at 2 years; longer-term follow-up may reveal different findings. For instance, although 2 years was likely sufficient to evaluate stress shielding, it is possible that stem loosening could increase with time, particularly in relation to polyethylene wear in TSAs. Fourth, this was not a prospective randomized study comparing different approaches to humeral component fixation. Fifth, the rate of adverse outcomes was low, so possible statistical significance of factors associated with them may not have been identified. In particular, we did not observe an association of adaptive changes or calcar osteolysis with glenoid loosening; this may be because of the 2-year follow-up and the relative lack of glenoid loosening observed at this time point. Sixth, although the radiographs were obtained in a systematic manner at the same institution, they were not fluoroscopically controlled and there may have been subtle differences in arm position that affected radiographic interpretation. Finally, the number of women who underwent a ream-and-run procedure was only 3, reflecting the relatively greater preference of men for this procedure; as a result, it is difficult to draw robust conclusions about the finding of higher adaptive changes for female patients with this procedure.

## Conclusion

An uncoated, standard-length, smooth humeral stem placed with impaction grafting is associated with a low risk of radiographic adaptive changes and a low radiographic risk of loosening at 2 years after shoulder arthroplasty. This study of impaction-grafted conventional humeral stems provides a basis against which the value of newer methods of humeral component fixation can be compared.

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