Does proximal porous coating in short-stem humeral arthroplasty reduce stress shielding?

Martin T Tan¹, John W Read² and Desmond J Bokor³

Abstract

Context: Short-stem humeral designs in shoulder arthroplasty have been introduced recently. A retrospective cohort study was conducted to determine if newer proximal porous titanium coating in humeral short stems produced clinical and radiologic improvements.

Method: Short-stem humeral implants (Tornier Ascend, Wright Medical) were used in 46 anatomical total shoulder replacements from October 2012 to December 2015. Clinical and radiologic measures were analyzed at one- and two-year follow-up.

Results: Nineteen shoulders received earlier grit blasted stems (Ascend Monolithic), and 27 shoulders received the later stems with proximal titanium porous coating (Ascend Flex). At two-year follow-up, radiographic changes and stress shielding were similar. Medial cortical thinning were more frequently observed in Monolithic (18 of 19) compared to Flex stems (19 of 27) on the PA films, though this was not statistically significant ($P = 0.061$). Clinical outcome scores improved regardless of the stem type used and independent of the radiologic adaptations on plain films. One participant with the Ascend Flex developed glenoid component failure and rotator cuff tear and was subsequently revised.

Discussion: Clinical and radiological outcomes are similar in both short-stem designs. Proximal titanium porous coating may reduce medial calcar cortical thinning but it does not prevent it.

Key message: When compared to similarly designed uncoated grit-blasted stems, proximally porous coated humeral short stems produced similar clinical and radiological results. The proximal titanium porous coating may reduce medial cortical thinning.

Keywords

shoulder, replacement, arthritis, press-fit, uncemented, mini-stem

Date received: 20th January 2018; revised: 14th March 2018; accepted: 22nd March 2018

Introduction

Anatomic total shoulder replacements (TSA) are performed for end stage glenohumeral osteoarthritis. In several arthroplasty registries, the number of shoulder arthroplasty procedures are increasing.^{1–3} Long-stem (also known as traditional-length stem) humeral prostheses were initially used for TSA. There are challenges with long stem prosthesis. (1) Cemented long stems can be challenging to revise if further interventions are needed. (2) Diaphyseal bone stock is sacrificed in the preparation of the canal for the long stem,⁴ which reduces available bone stock for future revisions or interventions if needed. (3) When preparing the canal, bone diaphyseal stress risers can develop,⁵ especially when asymmetric reaming of the shaft occurs, which

weakens the construct of the humeral shaft, predisposing to periprosthetic fracture.⁶ (4) Intra-operative fractures have been known to occur in about 5% of cases.⁷ As the diaphyseal portion of the humeral stem

¹Sydney Medical School, University of Sydney, Sydney, Australia

²Macquarie Medical Imaging, Macquarie University Hospital, Sydney, Australia

³Bone and Joint Clinical Program, Macquarie University Hospital, Sydney, Australia

Corresponding author:

Martin T Tan, Sydney Medical School, Edward Ford Building A27, The University of Sydney, NSW 2006, Australia.
Email: martin.tan.unsw@gmail.com

transfers load away from the proximal humerus, demineralization can develop around the proximal humerus, hence (5) the incidence of radiographic stress shielding and loosening at the proximal humerus can be as high as 82.5%.^{8,9} Raiss et al.¹⁰ found poorer clinical outcomes associated with osteolysis around the humeral stem.

The uncemented short-stem humerus had been designed in the last decade to overcome issues with the long-stem prosthesis. Harmer et al.⁴ proposed several advantages with short-stem implants, including (1) preserved bone stock, (2) reduced stress shielding, (3) no diaphyseal stress riser, and (4) easier removal of stem during revision surgery.

Recently, a few studies have published early short-term results of uncemented press-fit short-stem prostheses. In the early grit blasted short-stem design (Ascend Monolithic, Tornier, Wright Medical), radiographic loosening and stress shielding was found to occur in up to 71% of stems at two years post-operatively,¹¹ which raises concerns if these implants have adequate longevity and stability. A modification of the early design included a proximal titanium porous coating (Ascend Flex, Tornier, Wright Medical) with the aim of reducing stress shielding and loosening.

The aim of the study was to determine if proximal porous coating in the short-stem design will produce superior radiographic and clinical outcomes.

Subjects and methods

After ethics approval from Macquarie University Human Research and Ethics Committee (HREC reference 5201600763), a retrospective cohort study was conducted on consecutive total shoulder arthroplasties performed between October 2012 and December 2015 at two surgical centers—Macquarie University Hospital and Sydney Adventist Hospital. All surgeries were performed by the senior author, a fellowship trained shoulder surgeon (DB). Participants provided written consent for their clinical and radiographic data to be used for the study.

Participants

Inclusion criteria for the study were: (1) patients undergoing primary TSA, (2) diagnosis of primary glenohumeral osteoarthritis; (3) two-year post-operative radiographic and clinical follow-up; (4) a short-stem humerus implant from the same implant company (Tornier, Wright Medical, Montbonnot-Saint-Martin, France) used for surgery. Exclusion criteria include (1) patients with revision arthroplasty; (2) cemented arthroplasty; (3) patients lost to two-year follow-up for various reasons; (4) diagnosis other than primary

glenohumeral osteoarthritis; (5) hemiarthroplasty or reverse arthroplasty.

Surgical technique

Surgery was performed in a similar fashion for all participants, who received one of two designs of the anatomic press-fit Tornier Ascend humeral short stems (Ascend Monolithic or Ascend Flex). The primary surgeon used the Ascend Monolithic stems for patients operated from October 2012 to October 2013, and gradually used the Ascend Flex stem from January 2013 to December 2015. The primary surgeon had gained prior surgical experience using the Ascend Monolithic stem when the new Ascend Flex stem was utilized later.

A beach chair position was used, and a deltopectoral approach was utilized. The conjoint tendon was retracted, biceps tenotomy was performed, and subscapularis tendon taken down from the lesser tuberosity with the capsule to expose the glenohumeral joint. The glenohumeral joint was dislocated to expose the humeral head, large bony osteophytes were removed, and then the humeral head was resected. The humerus was then prepared. Sounders were used to compact bone and determine the upper size limit of the distal humerus, following which a metaphyseal punch was used to score cancellous bone at the metaphysis, then a metaphyseal compactor was used to prepare the metaphyseal bed. A humeral cut protector was then secured on the compactor stem. The glenoid was exposed and an appropriately sized pegged glenoid component (Aequalis PerFORM, Tornier, Montbonnot-Saint-Martin, France) was cemented (CMW 2 Gentamicin bone cement, DePuy International Ltd, Blackpool, England). Subsequently, a trial reduction was performed with the expected humeral head size before implantation of the definitive humeral components (Humeral head Calotte Humérale Aequalis CoCr, Tornier, Montbonnot-Saint-Martin, France). Transosseous sutures were used to repair the subscapularis tendon, and the biceps was tenodesed to the upper part of the pectoralis major tendon. A drain was inserted, hemostasis was achieved, and wound closure was performed with subcutaneous vicryl and subcuticular PDS. The arm was placed into a Velpeau sling with cryocuff and patient returned to recovery. Patients had a post-operative radiograph performed on the same day of surgery. Post-operatively, patients underwent the same routine rehabilitation. This included assisted forward flexion and external rotation to neutral 1–4 weeks post-operatively, pendular exercises from 4 weeks, strengthening exercises 6–12 weeks, finally strengthening and stretching with elastic tubing or light weights from 3 months onwards.

Figure 1. The designs of Ascend Monolithic and Ascend Flex humeral short stems.

M, length of metaphysis, L, length of the stem. Reproduced with permission from Tornier, Wright Medical.

Humeral stem designs

Designs of the two implants are shown in Figure 1. Both implants have a grit-blasted surface throughout the length of the stem to promote bony on-growth. The Ascend Monolithic has a press-fit taper between the proximal metaphysis (41% of the length of the stem) and diaphysis. The Ascend Flex has a proximal titanium porous coating (36% length of the stem) in addition to the grit-blasted surface. The porous coating has an average pore size of 365 μm , porosity 30–45%, to increase the surface area for bony in-growth. Both implants are made of Ti-6AL-4V alloy. The Ascend Flex implant has a female taper, which allows a conversion from anatomic to reverse shoulder replacement. Both stems were implanted with identical surgical instrumentation.

Clinical evaluation

Participants were seen pre-operatively and post-operatively at six weeks, three months, six months, one-year, and two-year follow-up visits. At the post-operative one-year and two-year visits, validated clinical outcome measures were obtained. This included the Constant Score, American Shoulder and Elbow Surgeons (ASES) score, Western Ontario Osteoarthritis Score (WOOS), and Single Assessment Numeric evaluation (SANE). Participants were also asked to rate how satisfied they were with their shoulder, ranging from very dissatisfied, dissatisfied, satisfied to very satisfied. Range of motion was measured with a goniometer and strength with a handheld dynamometer (Ametek Chantillon 200 Digital Force Gauge, USA).

Radiographic evaluation

Plain film X-rays were taken with the standard poster-anterior (PA), scapular Y-, and axillary views.

Figure 2. Radiographic measurements on PA view.

C, center of humeral head. AHD, acromio-humeral distance; subs, subsidence; θ , stem inclination; FR_{met} and FR_{dia} , metaphyseal and diaphyseal filling ratio respectively; S_{met} and S_{dia} , widths of stem at metaphysis and diaphysis; h_{met} and h_{dia} , humeral widths at metaphysis and diaphysis; l , length from C to stem tip.

Radiographs were digitally captured and analyzed on a digital film viewing software IntelViewer™ version 4 (Intelrad Medical Systems, Montreal, Canada). Only PA and axillary views that had sufficient detail for radiographic measurements and stress shielding analysis were used in study.

On the PA views, radiographic measurements, illustrated in Figure 2, that were recorded included the acromio-humeral distance (AHD), stem subsidence (subs) described previously by Merolla et al.,¹² and also the stem inclination (θ), filling ratio of the stem at the metaphysis (FR_{met}), and diaphysis (FR_{dia}), with the method previously described by Schnetzke et al.¹³

The radiographs were analyzed for the following features of stress shielding and radiographic adaptation: cortical thinning and/or osteopenia (CT), radiolucent lines (RLL), spot welding (SW), condensation lines (CL) at five zones around the humeral stem (Figure 3). In addition, we observed and recorded intra-cortical tunneling (ICT), a radiographic feature reflecting bone turnover.¹⁴ Examples of radiological changes are shown in Figure 4. On the PA view, the zones around the stem analyzed were superomedially (M1), inferomedially (M2), superolaterally (L1), inferolaterally (L2), and under stem (US). On the axillary view, the zones included anterosuperiorly (A1), anteroinferiorly (A2), posterosuperiorly (P1), posteroinferiorly

Figure 3. Zones around the humeral stem analyzed for radiographic features of stress shielding. C, geometric center of the head.

Figure 4. Radiographic changes. (a) cortical thinning (CT) observed between one- and two-year follow-up visits; (b) condensation line (CL) below the stem; (c) radiolucent lines (RLL); (d) spot welding (SW) at the distal stem; and (e) intracortical tunneling (ICT).

(P2), and under the stem (Ax-US). These defined zones around the humeral stem were adapted from previous studies and recent recommendations.^{13,15} The degree of radiologic adaptations on the PA film was classified as low (1–3 changes) or high (more than 3). This method of analysis was used in an earlier study on humeral short stems by Schnetzke et al.¹³ Radiographic changes of the glenoid were assessed according to the criteria described by Lazarus et al.,¹⁶ based on the number of radiolucent lines around the pegs (Table 1).

All radiographs were de-identified and blinded, and were analyzed by the lead author and an experienced radiologist (JR). In case of a disagreement on a radiographic finding, the films were reviewed again and a consensus was reached.

Table 1. Assessment of glenoid component loosening according to Lazarus et al.¹⁶

Grade	Finding
0	No radiolucency
1	Incomplete radiolucency around one or two pegs
2	Complete radiolucency (≤ 2 mm wide) around one peg only, with or without incomplete radiolucency around one other peg
3	Complete radiolucency (≤ 2 mm wide) around two or more pegs
4	Complete radiolucency (> 2 mm wide) around two or more pegs
5	Gross loosening

Statistical analysis

Results were analyzed with statistical software GraphPad Prism version 7.02 (GraphPad Software Inc., California, USA) and Statistical Package for Social Sciences (SPSS) version 24 (IBM Corporation, New York, USA). Results are reported as mean $\pm$ standard error of mean. Statistical significance was set at 0.05. Student's *t*-test was used for comparing means in the parametric data, and Wilcoxon rank sum test for comparing the nonparametric data. Categorical data were analyzed using the Fisher's exact test, and correlations with linear regression analysis. Interobserver agreement was calculated with Cohen's coefficient of agreement (κ),¹⁷ with agreement strength inferred according to Landis and Koch.¹⁸

Results

The senior author performed 66 anatomic total shoulder arthroplasties in 62 patients. Seven patients refused participation in the study, one died of unrelated cause, and ten patients did not attend the two-year follow-up due to personal reasons, such as changing place of residence, and difficulty in attending the follow-up X-rays. Several attempts were made to contact patients and facilitate follow-up visits if patients found difficulty in attending the follow-up visits, such as finding clinics and practices closer to patient's residence. One patient had rheumatoid arthritis of the shoulder, another had a cemented stem, and thus both were excluded. In total, 46 shoulders in 41 participants were suitable for analysis (19 Ascend Monolithic, 27 Ascend Flex). Participant characteristics are shown in Table 2.

With regard to the radiographic analysis, interobserver reliability was high ($\kappa = 0.91$, agreement = 96%). There were no significant differences in the number of radiographic changes observed between both stems at

Table 2. Participant characteristics.

	Ascend Monolithic	Ascend Flex	P-value
Number of patients	19	27	
Age (years)	67.9 $\pm$ 1.6	71.7 $\pm$ 1.4	0.080
Gender	10 males: 9 females	15 males: 12 females	>0.999
Operated arm	10 right, 9 left	13 left, 14 right	
Handedness	19 right, 0 left	14 right, 2 left, 1 ambidextrous	
Dominant hand operated on	10	16	0.766
Follow-up length	2.39 $\pm$ 0.14	2.18 $\pm$ 0.07	0.155

Table 3. Radiologic adaptations.

PA view Zones	Ascend Monolithic (19 patients)		Ascend Flex (27 patients)	
	13 films One-year	19 films Two-year	27 films One-year	27 films Two-year
M1	CT = 11 ICT = 3	CT = 18* ICT = 5 SW = 1	CT = 16 ICT = 14	CT = 19* ICT = 8
L1	CT = 9 SW = 3	CT = 16 ICT = 1 CL = 1	CT = 15 ICT = 1	CT = 20
M2	CT = 4 ICT = 1 SW = 3	CT = 11 ICT = 3 RLL = 1 SW = 14	CT = 8 ICT = 6 SW = 5	CT = 10 ICT = 7 RLL = 1 SW = 18
L2	CT = 5 SW = 3 CL = 1	CT = 14 RLL = 1 SW = 12	CT = 4 RLL = 2 SW = 12	CT = 20 ICT = 1 RLL = 3 SW = 22
US		CL = 2	RLL = 1 CL = 1	CL = 1
Glenoid (median Lazarus score)	0	1	0	2
Adaptations ^a	5 high 8 low	16 high 3 low	10 high 17 low	20 high 7 low
Axillary view	One-year (4 films)	Two-year (7 films)	One-year (4 films)	Two-year (14 films)
A1	CT = 1	CT = 3	CT = 1 ICT = 1	CT = 10 ICT = 2
P1	CT = 3 ICT = 1	CT = 7	CT = 1	CT = 12 ICT = 1
A2	SW = 1	ICT = 1 SW = 4	SW = 1	CT = 1 ICT = 1 SW = 10
P2	CT = 2 ICT = 1	CT = 2 ICT = 4	CT = 1 ICT = 1	CT = 1 ICT = 3 RLL = 1 SW = 9 CL = 1
Ax-US				CL = 1

*Comparison between groups $P = 0.061$ (OR = 7.58, confidence interval = 1.1–88.1).

^aRadiologic adaptations: graded low if 1–3 changes, and high if > 3 changes, or aggressive behavior.

CT: cortical thinning; CL: condensation line; RLL: radiolucent lines; SW: spot welding; ICT: intracortical tunneling.

one- and two-year follow-up (Table 3). In the PA radiographs, 16 of 19 with the Ascend Monolithic stems, and 20 of 27 of the Ascend Flex stems had high levels of radiologic adaptation (>3 radiographic changes

observed). Almost all radiographs with the Ascend Monolithic stems (18 of 19) were observed to have cortical thinning at the medial calcar region (M1), compared to 19 of 27 Ascend Flex stems. However, this

Table 4. Radiographic measures.

	Ascend Monolithic			Ascend Flex		
	Pre-operative	One-year	Two-year	Pre-operative	One-year	Two-year
Acromiohumeral distance (mm)	10 ± 3	9 ± 1	9 ± 1	10 ± 1	9 ± 1	9 ± 1
Subsidence (mm)	5 ± 3	5 ± 1	4 ± 1	4 ± 0	4 ± 0	5 ± 0
Filling ratio at metaphysis (FR _{met})	0.57 ± 0.01	0.61 ± 0.01	0.62 ± 0.01 ^a	0.6 ± 0.01	0.64 ± 0.01 ^b	0.64 ± 0.01 ^c
Within groups		0.114	0.002		0.002	0.001
Filling ratio at diaphysis (FR _{dia})	0.64 ± 0.06	0.65 ± 0.01	0.66 ± 0.01 ^d	0.7 ± 0.01	0.68 ± 0.01	0.68 ± 0.01 ^e
Stem inclination (°)	4 ± 1	4 ± 1	4 ± 1	3 ± 0	4 ± 1	4 ± 1

^{a-c}Significant difference in FR_{met} compared to pre-operative levels: ^a*P* = 0.002, ^b*P* = 0.002, ^c*P* = 0.001.

^{d,e}Significant difference in FR_{dia} compared to pre-operative levels: ^d*P* = 0.01, ^e*P* = 0.01.

difference did not reach statistical significance (Fisher's exact test: *P* = 0.061, OR = 7.58, CI = 1.1–88.1). The most common radiographic changes were cortical thinning proximally at M1 and L1, and spot welding distally at M2 and L2. Compared to the early post-operative measurements, the filling ratio at the metaphysis and diaphysis increased at the two-year follow-up in both groups (5% in Ascend Monolithic, 4% in Ascend Flex). Acromio-humeral distance, stem subsidence, and stem inclination did not change (Table 4). On the axillary views in both stems, the most common changes were cortical thinning proximally (A1 and P1) and spot welding distally (A2 and P2). As a small number of suitable axillary films were available for analysis, an accurate statistical comparison between both groups could not be made.

There were significant improvements in all clinical outcome scores and range of motion at the one- and two-year follow-up visits (*P* < 0.001), with no significant differences between both groups (Table 5). The pre-operative constant score was higher in participants with the Ascend Flex compared to participants with the Ascend Monolithic (*P* < 0.0001), but there were no differences in other scores pre- and post-operatively. Neither the extent of radiologic adaptations nor the stem filling ratio correlated with the clinical outcome scores or shoulder range of motion.

One post-operative complication was observed in a participant with the Ascend Flex. This was the only stem found radiographically to be at risk of loosening. The participant presented at the two-year follow-up with increasing pain, weakness, and restriction of the shoulder. Ultrasound scan demonstrated a torn rotator cuff tendon, and radiographs showed fracture of the

glenoid component and medial calcar thinning (Figure 5). The participant underwent a revision reverse shoulder arthroplasty. Intra-operatively, the short stem was found to be securely fixed to bone and therefore a cortical window had to be created intra-operatively to access and remove the short stem. A cemented long humeral stem was inserted during the revision.

Discussion

In the orthopedic literature, short-stem humeral designs have been shown to produce good clinical outcomes in the short- to medium-term follow-up, despite variable radiographic outcomes. This study showed that proximal porous titanium coating on the short stem design (Ascend Flex) does not produce superior radiographic or clinical outcomes, compared to a comparable uncoated grit blasted short stem design (Ascend Monolithic). Proximal porous titanium coating may, however, reduce medial cortical thinning.

Denard et al.¹⁹ recently demonstrated in a retrospective study that cortical thinning was more common in long-stem prosthesis in comparison with short-stem (74% versus 55%). Several designs of the short-stem implants have been introduced in the last decade to overcome the challenges and complications associated with the long-stem designs. Studies on these short-stem implants are shown in Table 6.^{11,13,20–29}

Stress shielding, as described by Wolff et al.,³⁰ is the adaptation of bone to material with different mechanical properties. The first case series on the uncoated Ascend Monolithic stems showed high rates of stress shielding and radiologic adaptations on follow-up radiographs, occurring in up to 71% of stems.¹¹

Table 5. Clinical outcome measures.

	Ascend Monolithic			Ascend Flex		
	Pre-operative	One-year	Two-year	Pre-operative	One-year	Two-year
Constant score	13 ± 3	79 ± 2*	80 ± 1*	32 ± 2**	72 ± 2*	76 ± 2*
ASES	43 ± 3	92 ± 2*	96 ± 1*	44 ± 3	79 ± 5*	91 ± 2*
WOOS	69 ± 3	4 ± 1*	0 ± 0*	67 ± 4	13 ± 4*	8 ± 4*
Satisfaction	I	4*	4*	I	4*	4*
SANE	35 ± 5	94 ± 2*	95 ± 1*	33 ± 4	83 ± 3*	86 ± 5*
Forward flexion (°)	99 ± 6	149 ± 4*	154 ± 3*	105 ± 5	151 ± 3*	149 ± 3*
Abduction (°)	80 ± 4	142 ± 7*	151 ± 5*	80 ± 5	142 ± 5*	146 ± 4*
External rotation (°)	7 ± 3	32 ± 4*	37 ± 2*	18 ± 4	41 ± 2*	42 ± 2*

*P-value significant when compared to preoperative measurements.

**P-value significant when comparison is made between groups.

ASES: American Shoulder and Elbow Surgeons score; WOOS: Western Ontario Osteoarthritis Score; SANE: Single Assessment Numeric Method.

Figure 5. (a) Post-operative appearance of an Ascend Flex prosthesis. (b) Two-year follow-up showing glenoid component fracture and lucency (→), and significant medial calcar osteolysis (⇒). (c) Revision to a reverse arthroplasty with a long stem.

Subsequent studies on the Ascend Monolithic stems also found high rates of stress shielding, and medial calcar osteolysis.^{13,28,29} We found similar findings in our study, where 16 of 19 stems showed high rates of radiologic stress shielding at two-year follow-up.

The short-stem design was therefore modified to include a proximal porous titanium coating with the aim of producing a stable osseointegrative implant (Ascend Flex). Titanium alloys, first developed for use in aircraft, became available for orthopedic use in the 1940s.³¹ Among metals, titanium has a low modulus of elasticity (Ti-6Al-4V modulus = 116–120 GPa). Low modulus materials used close to bone

(bone modulus = 15.5–18.6 GPa) reduces stress shielding, as uniform stress transfer occurs between implant to bone.³² Ti-6Al-4V, which is a titanium alloy consisting of 6% aluminum and 4% vanadium, have been used for femoral stems in hip arthroplasty. These uncemented titanium coated stems showed low rates of osteolysis, radiolucency, and loosening at long-term follow-up of up to 10 years.³³

Recent studies on short-stem designs with porous titanium coating have shown promising results. Low rates of radiologic stress shielding have been observed. Cortical thinning around the medial calcar region have been shown to be reduced compared to uncoated

Table 6. Clinical studies on short-stem humeral implants.

Company	Short-stem design	Clinical trials
Zimmer Biomet	Verso Comprehensive Mini	Atoun et al. ²⁰ Jost et al. ²¹ Giuseffi et al. ²²
Arthrex	Univers Apex	Denard et al. ²³ Romeo et al. ²⁴
Tornier	Ascend Aequalis (Monolithic/Flex)	Casangrande et al. ¹¹ Schnetzke et al. ¹³ Schnetzke et al. ²⁵ Schnetzke et al. ²⁶ Goetzmann et al. ²⁷ Denard et al. ²³ Morwood et al. ²⁸ Szerlip et al. ²⁹

designs.^{28,29} Similarly, we found proximally porous coated stems (Ascend Flex) had lower rates of medial calcar thinning, and almost all the stems without coating (Ascend Monolithic) had medial calcar thinning. Medial calcar resorption is thought to be an adaptation of bone to differing stress distribution according to Wolff's law;³⁰ however, the true significance of this phenomenon, and its association with implant failure or periprosthetic fracture is still unknown. Raiss et al.¹⁰ found long humeral stems with osteolysis correlated with poor clinical outcome at long term follow-up of at least five years. However, recent studies on short-stem designs found no correlation of medial cortical thinning to clinical outcome in the short- to medium-term follow-up of about two years.^{28,29} We found only one participant who presented with aggressive medial calcar osteolysis, rotator cuff tear and glenoid component failure, with unsatisfactory clinical shoulder function, who subsequently had revision arthroplasty to a long stem. Despite radiographic findings, which suggested stem loosening in this participant, a securely fixed stem was found intraoperatively. Hence, complications in this participant seemed to be related to glenoid component failure and rotator cuff tear rather than failure of humeral fixation. Long-term studies will be needed to determine the clinical significance of medial calcar thinning in these short stems.

A higher filling ratio of the stem is thought to be associated with higher rates of radiologic stress shielding.^{13,26} We did not observe this association. However, we found that the filling ratio of the stem increased slightly (by 4–5%) at the two-year follow-up visits compared to early post-operative radiographs, suggesting some cortical resorption occurring in most of the stems over two years.

In our study, we found patterns of stress shielding similar to what other studies had found in the orthopaedic literature – proximal cortical thinning and distal spot welding.¹³ Additionally, we observed intracortical tunneling occurring on the radiographs (Figure 4). This phenomenon, seen as longitudinal striations in the subendosteal bone has been well described in the radiology literature.^{14,34–36} It is observed in states of rapid bone turnover due to intracortical bone resorption, observed in patients with hyperparathyroidism, osteomalacia, renal osteodystrophy, and disuse or reflex sympathetic dystrophy. Intracortical tunneling may reflect bony adaptation and remodeling as bone adapts to changing mechanical environment according to Wolff's law. However, we did not find any associations of intracortical tunneling with clinical or other radiologic parameters, and hence its significance is still unknown.

There are limitations in our study. There was no randomization of stem type used, and participant numbers were small with a relatively short follow-up period. As participants who presented for shoulder arthroplasty later received the newer stem design with porous coating (Ascend Flex), the primary surgeon will also have gained more surgical experience with implanting short stems. The analysis of the axillary view films were also unfortunately limited due to the small number of films suitable for analysis, hence a meaningful comparison of radiologic changes in both stems on the axillary view could not be made.

Strengths of our study include strict inclusion and exclusion criteria. Only patients with primary glenohumeral arthritis undergoing primary arthroplasty were included, to avoid potential confounders such as fractures, post-traumatic arthritis, and rheumatoid arthritis.^{37,38} Radiographs were assessed by both the chief investigator and an independent radiographer with excellent interobserver reliability. A single surgeon operated on all shoulders, ensuring consistency in the operative method.

In conclusion, improvements in clinical outcomes are observed with anatomic total shoulder arthroplasty with uncemented press fit short-stem humeral designs, independent of radiologic outcomes. Radiologic adaptations and cortical resorption are observed regardless of the stem design. Medial calcar thinning may be reduced, but certainly not prevented by proximal titanium porous coating. Studies with longer follow-up will be needed to determine if radiologic changes produce any significant clinical effects.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethical Review and Patient Consent

Ethics approval was granted by the Macquaire University Human Research Ethics Committee (HREC) Medical Sciences. Reference No. 5201600763. Written participant consent was obtained in accordance with the HREC requirements.

References

1. Australian Orthopaedic Association. *National Joint Replacement Registry (AOANJRR). Hip, knee & shoulder arthroplasty: 2017 annual report*. Adelaide, Australia: AOA, 2017.
2. Dutch Arthroplasty Register (LROI). *Online LROI annual report 2017: 10 years of registration, a wealth of information*. Online Report. Bruistensingel, The Netherlands: LROI, 2017.
3. National Joint Registry. *14th annual report 2017. National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. Surgical data to 31 December 2016*. United Kingdom, 2017.
4. Harmer L, Throckmorton T and Sperling JW. Total shoulder arthroplasty: Are the humeral components getting shorter? *Curr Rev Musculoskelet Med* 2016; 9: 17–22.
5. Lee M, Chebli C, Mounce D, et al. Intramedullary reaming for press-fit fixation of a humeral component removes cortical bone asymmetrically. *J Shoulder Elbow Surg* 2008; 17: 150–155.
6. Singh JA, Sperling J, Schleck C, et al. Periprosthetic fractures associated with primary total shoulder arthroplasty and primary humeral head replacement: A thirty-three-year study. *J Bone Joint Surg Am* 2012; 94: 1777–1785.
7. Bohsali KI, Wirth MA and Rockwood CA. Complications of total shoulder arthroplasty. *J Bone Joint Surg Am* 2006; 88: 2279–2292.
8. Inoue K, Suenaga N, Oizumi N, et al. Humeral bone resorption after anatomic shoulder arthroplasty using an uncemented stem. *J Shoulder Elbow Surg* 2017; 26: 1984–1989.
9. Merolla G. Shoulder replacement in advanced glenohumeral osteoarthritis: Current concepts review. *OA Orthop* 2013; 1: 7.
10. Raiss P, Edwards TB, Deutsch A, et al. Radiographic changes around humeral components in shoulder arthroplasty. *J Bone Joint Surg Am* 2014; 96: e54.
11. Casagrande DJ, Parks DL, Torngren T, et al. Radiographic evaluation of short-stem press-fit total shoulder arthroplasty: Short-term follow-up. *J Shoulder Elbow Surg* 2016; 25: 1163–1169.
12. Merolla G, Di Pietto F, Romano S, et al. Radiographic analysis of shoulder anatomical arthroplasty. *Eur J Radiol* 2008; 68: 159–169.
13. Schnetzke M, Coda S, Raiss P, et al. Radiologic bone adaptations on a cementless short-stem shoulder prosthesis. *J Shoulder Elbow Surg* 2016; 25: 650–657.
14. Grampp S. *Radiology of osteoporosis*, 2nd ed. Berlin, Geidelberg: Springer, 2008.
15. Denard PJ, Raiss P, Gobeze R, et al. Stress shielding of the humerus in press-fit anatomic shoulder arthroplasty: Review and recommendations for evaluation. *J Shoulder Elbow Surg*, Epub ahead of print 5 February 2018. DOI: 10.1016/j.jse.2017.12.020.
16. Lazarus MD, Jensen KL, Southworth C, et al. The radiographic evaluation of keeled and pegged glenoid component insertion. *J Bone Joint Surg Am* 2002; 84-A: 1174–1182.
17. Cohen J. A coefficient of agreement for nominal scales. *Educ Psychol Meas* 1960; 20: 37–46.
18. Landis JR and Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33: 159–174.
19. Denard PJ, Noyes MP, Walker JB, et al. Proximal stress shielding is decreased with a short stem compared with a traditional-length stem in total shoulder arthroplasty. *J Shoulder Elbow Surg*, Epub ahead of print 30 August 2017. DOI: 10.1016/j.jse.2017.06.042.
20. Atoun E, Van Tongel A, Hous N, et al. Reverse shoulder arthroplasty with a short metaphyseal humeral stem. *Int Orthop* 2014; 38: 1213–1218.
21. Jost PW, Dines JS, Griffith MH, et al. Total shoulder arthroplasty utilizing mini-stem humeral components: Technique and short-term results. *HSS J Musculoskelet J Hosp Spec Surg* 2011; 7: 213–217.
22. Giuseffi SA, Streubel P, Sperling J, et al. Short-stem uncemented primary reverse shoulder arthroplasty: Clinical and radiological outcomes. *Bone Jt J* 2014; 96-B: 526–529.
23. Denard PJ, Noyes MP, Walker JB, et al. Radiographic changes differ between two different short press-fit humeral stem designs in total shoulder arthroplasty. *J Shoulder Elbow Surg*, Epub ahead of print 28 September 2017. DOI: 10.1016/j.jse.2017.08.010.
24. Romeo AA, Thorsness RJ, Sumner SA, et al. Short-term clinical outcome of an anatomic short-stem humeral component in total shoulder arthroplasty. *J Shoulder Elbow Surg*, Epub ahead of print 19 July 2017. DOI: 10.1016/j.jse.2017.05.026.
25. Schnetzke M, Coda S, Walch G, et al. Clinical and radiological results of a cementless short stem shoulder prosthesis at minimum follow-up of two years. *Int Orthop* 2015; 39: 1351–1357.
26. Schnetzke M, Preis A, Coda S, et al. Anatomical and reverse shoulder replacement with a convertible, uncemented short-stem shoulder prosthesis: First clinical and radiological results. *Arch Orthop Trauma Surg* 2017; 137: 679–684.
27. Goetzmann T, Molé D, Aisene B, et al. A short and convertible humeral stem for shoulder arthroplasty: Preliminary results. *J Shoulder Elb Arthroplasty* 2017; 1: 2471549217722723.
28. Morwood MP, Johnston PS and Garrigues GE. Proximal ingrowth coating decreases risk of loosening following

- uncemented shoulder arthroplasty using mini-stem humeral components and lesser tuberosity osteotomy. *J Shoulder Elbow Surg* 2017; 26: 1246–1252.
29. Szerlip BW, Morris BJ, Laughlin MS, et al. Clinical and radiographic outcomes after total shoulder arthroplasty with an anatomic press-fit short stem. *J Shoulder Elbow Surg* 2018; 27: 10–16.
 30. Wolff J. *The law of bone remodelling*. Heidelberg: Springer, 1986.
 31. Ratner BD, Hoffman AS, Schoen FJ, et al. *Biomaterials science: An introduction to materials in medicine*. San Diego, CA: Elsevier Science, 2012.
 32. Petersen RC. Titanium implant osseointegration problems with alternate solutions using epoxy/carbon-fiber-reinforced composite. *Metals* 2014; 4: 549–569.
 33. Archibeck MJ, Berger RA, Jacobs JJ, et al. Second-generation cementless total hip arthroplasty. Eight to eleven-year results. *J Bone Joint Surg Am* 2001; 83-A: 1666–1673.
 34. Meema HE and Schatz DL. Simple radiologic demonstration of cortical bone loss in thyrotoxicosis. *Radiology* 1970; 97: 9–15.
 35. Steinbach HI, Gordan GS, Eisenberg E, et al. Primary hyperparathyroidism: A correlation of roentgen, clinical, and pathologic features. *Am J Roentgenol* 1961; 14: 329–343.
 36. Genant HK, Kozin F, Bekerman C, et al. The reflex sympathetic dystrophy syndrome. A comprehensive analysis using fine-detail radiography, photon absorptiometry, and bone and joint scintigraphy. *Radiology* 1975; 117: 21–32.
 37. Barlow JD, Yuan BJ, Schleck CD, et al. Shoulder arthroplasty for rheumatoid arthritis: 303 consecutive cases with minimum 5-year follow-up. *J Shoulder Elbow Surg* 2014; 23: 791–799.
 38. Farnig E, Zingmond D, Krenek L, et al. Factors predicting complication rates after primary shoulder arthroplasty. *J Shoulder Elbow Surg* 2011; 20: 557–563.