Impact of screw length and screw quantity on reverse total shoulder arthroplasty glenoid fixation for 2 different sizes of glenoid baseplates

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ARTICLE INFO

Background: Little guidance exists regarding the minimum screw length and screw quantity necessary to achieve fixation in reverse total shoulder arthroplasty (rTSA); to that end, this study quantified the displacement of 2 different sizes of glenoid baseplates using multiple different screw lengths and quantities of screws in a low-density polyurethane bone-substitute model.

Methods: Testing of rTSA glenoid loosening was conducted according to ASTM F 2028-17. To independently evaluate the impact of screw quantity and screw length on rTSA glenoid fixation for 2 different sizes of glenoid baseplates, baseplates were constructed using 2 screws, 4 screws, or 6 screws (with the latter being used for the larger baseplate only) with 3 different poly-axial locking compression screw lengths.

Results: Both sizes of glenoid baseplates remained well fixed after cyclic loading regardless of screw length or screw quantity. Baseplates with 2 screws had significantly greater displacement than baseplates with 4 or 6 screws. No differences were observed between baseplates with 4 screws and those with 6 screws (used for the larger baseplate). Both sizes of baseplates with 18-mm screws had significantly greater displacement than baseplates with 30- or 46-mm screws. For larger baseplates, those with 30-mm screws had significantly greater displacement than those with 46-mm screws in the superior-inferior direction.

Discussion: For the 2 different sizes of baseplates tested in this study, rTSA glenoid fixation was impacted by both screw quantity and screw length. Irrespective of screw quantity, longer screws showed significantly better fixation. Irrespective of screw length, the use of more screws showed significantly better fixation, up to a point, as the use of more than 4 screws showed no incremental benefit. Finally, longer screws can be used as a substitute for additional fixation if it is not feasible to use more screws.

Aseptic glenoid loosening is a common failure mode of reverse total shoulder arthroplasty (rTSA), with a reported incidence of 1% to 12% and an average incidence of less than 5%.[8,10,37,43,45] Adequate initial fixation is critical to obtain a stable bone-implant interface and permit osseointegration during the first few months after surgery.[4,17,29] Achieving adequate initial glenoid fixation can be challenging as rTSA is commonly used in elderly patients with osteoporosis and increasingly used in scapulae with significant bony defects. It has previously been shown that rTSA glenoid fixation is impaired by its use in lower-density bone or substrates,[38,39] by its use with baseplates of smaller surface area,[32,38,39] and when used in glenoids or scapulae with defects of various types and sizes.[7,8,33-35]

To aid the surgeon in achieving initial fixation in these various conditions and morphologies, multiple rTSA baseplate designs of different sizes are available in the marketplace. These prostheses offer between 2- and 6-screw options, with each screw hole

accepting a locking and/or compression screw of varying lengths between 15 and 50 mm. Despite the availability of multiple implant sizes, little guidance exists regarding the minimum screw length and/or minimum quantity of screws necessary to achieve fixation in rTSA. A biomechanical test method was previously devised to aid surgeons in comparatively evaluating such questions related to rTSA glenoid fixation.[3,30] The goal of this biomechanical study was to quantify the displacement, before and after cyclic loading, of 2 different sizes of glenoid baseplates associated with multiple different screw lengths and numbers of screws used to obtain fixation in a low-density (0.24-g/cm^3) polyurethane bone-substitute model.

Materials and methods

Testing of rTSA glenoid loosening was conducted according to ASTM F 2028-17.[3] We quantified the baseplate displacement of the Equinoxe reverse shoulder prosthesis (Exactech, Gainesville, FL, USA) for 2 different sizes of glenoid baseplates (Fig. 1) before and after cyclic loading with an applied load of 750 N for 10,000 cycles. A 42 × 23–mm glenosphere was used with the standard baseplate whereas a 40 × 22–mm glenosphere was used with the small baseplate so that each device lateralized the center of rotation from the glenoid by approximately 2 mm. To independently evaluate the impact of screw quantity and screw length on rTSA glenoid fixation for each baseplate size, the standard baseplates were constructed using 2, 4, and 6 screws with each of 3 different poly-axial locking compression screw lengths: 4.5 × 18 mm (n = 15), 4.5 × 30 mm (n = 15), and 4.5 × 46 mm (n = 15). Five of each of the screw quantity–screw length configurations were tested for a total of 45 standard baseplate specimens. In addition, the small baseplates were constructed using 2 and 4 screws with each of 3 different poly-axial locking compression screw lengths: 4.5 × 18 mm (n = 10), 4.5 × 30 mm (n = 10), and 4.5 × 46 mm (n = 10). Five of each of the screw quantity–screw length configurations were tested, for a total of 30 small baseplate specimens.

Each of these different configurations was tested in a low-density (0.24-g/cm^3) polyurethane bone-substitute block (part No. 1521-419, 76 mm × 57 mm × 48 mm; Pacific Research Laboratories, Vashon, WA, USA), conforming to ASTM F 1839.[2] All baseplates were fully backside supported by the polyurethane bone-substitute block. This low-density substrate is intended to mimic the modulus, density, and strength range typical of an elderly patient with osteoporosis receiving reverse shoulder arthroplasty, with poor-quality glenoid bone.[1,2,18,22,24] A polyurethane bone-substitute block was selected as the best testing substrate to ensure a uniform comparison between short and long screws. The use of a polyurethane block was deemed to provide the most uniform substrate for comparison of the 75 test specimens; the use of a composite scapula was considered but decided against as the use of longer screws would have resulted in "bicortical" fixation in some baseplate positions, whereas shorter screws in the same position would have only achieved "unicortical" fixation. Each glenoid baseplate was secured to the polyurethane bone-substitute block using the same manufacturer-specified surgical technique: A 7.3-mm drill was used to prepare the hole to press-fit the tapered cage peg, and a 3.2-mm drill was used to create the pilot hole for each 4.5-mm-diameter compressive screw. Each screw in each baseplate was always oriented in the center of each hole in the same direction relative to its placement on the baseplate, regardless of the length of screw used. As depicted in Figure 2, the 2-screw configuration used the most superior and inferior screw holes in the small baseplate (not shown) and standard baseplate; the 4-screw configuration used all screw holes in the small baseplate (not shown) or the most superior and 3 most inferior screw holes in the standard baseplate; and the 6-screw configuration used all 6 available screw holes in the standard baseplate.

The reverse shoulder glenoid loosening method consisted of 2 tests—a displacement test (Figs. 3 and 4) and a cyclic test (Fig. 5)—and was conducted in 3 consecutive phases: (1) displacement test before cyclic loading, (2) cyclic test, and (3) displacement test after cyclic loading. In the displacement tests before and after cyclic loading, the axial test machine (Instron, Norwood, MA, USA; resolution of 1 μm) and 2 digital indicators (Mitutoyo, Kawasaki, Japan; resolution of 1 μm) measured displacement as a 100-N compressive axial load was applied perpendicular to the glenoid and a 357-N shear load was applied parallel to the face of the glenoid baseplate along its superior-inferior (SI) axis; this was then performed a second time, turning the component 90° and loading it along its anterior-posterior (AP) axis (Figs. 3 and 4). In the cyclic test, a 750-N

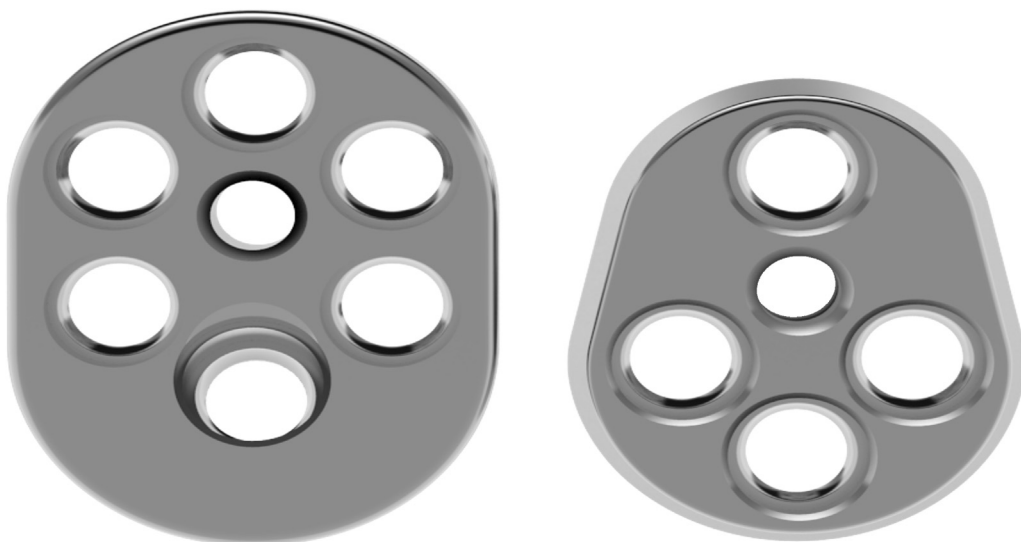**Figure 1** Standard glenoid baseplate (34 × 25 mm, *left*) and small glenoid baseplate (30 × 24 mm, *right*) used for this reverse total shoulder arthroplasty glenoid fixation test. Each glenoid baseplate is oriented from superior *(top)* to inferior *(bottom)*.
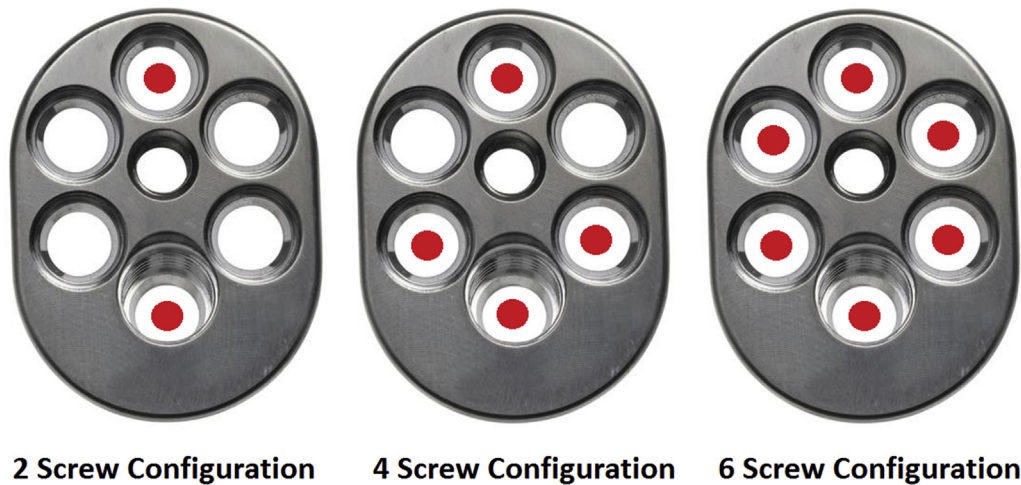
Figure 2 Standard-size glenoid baseplate screw locations used for each of the 2-, 4-, and 6-screw configurations tested for this reverse total shoulder arthroplasty glenoid fixation test.

axial load was constantly applied through the center of the humeral liner as the glenosphere, glenoid baseplate, and/or bone-substitute block were rotated about the humeral component with a stepper motor to create a sinusoidal angular displacement profile encompassing an arc of 55° at 0.5 Hz for 10,000 cycles (Figs. 4 and 5). The components were cooled with a continuous jet of air with no lubrication during the cyclic test. Failure was determined by catastrophic loosening of the baseplate from the polyurethane bone-substitute block.

Statistical analysis was performed in the Minitab package (version 18; Minitab, State College, PA, USA) using 1-way analysis of variance to compare baseplate displacement before and after cyclic loading in the SI and AP directions relative to the low-density block for both the standard and small baseplates. A post hoc Tukey pairwise comparison was run to determine the difference between categories and adjust for a type I error. Two-tailed unpaired Student t tests were used to perform comparisons between the standard and small baseplates, with significance defined as $P < .05$.
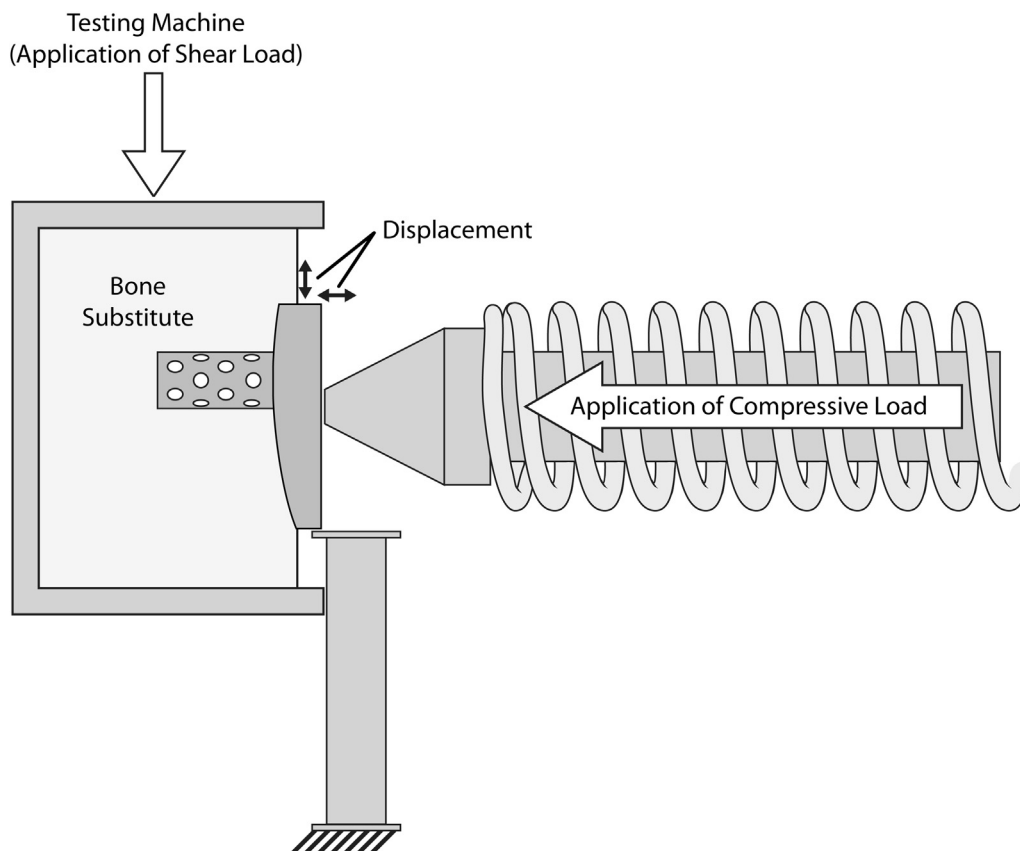

Figure 3 In the displacement test, shear and compressive loads were applied directly to the baseplate before and after cyclic loading.
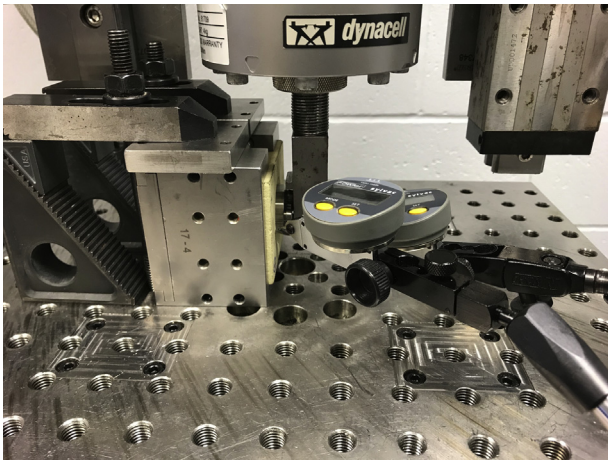
Figure 4 Displacement test. It should be noted that the translational stage is providing a 100-N compressive force and the actuator of the load frame is providing a 357-N shear force.

Results

All glenoid baseplates remained well fixed after cyclic loading in the low-density bone-substitute model, regardless of the baseplate size, screw length, or quantity of screws used to obtain fixation. Tables I and II describe the impact of screw quantity on baseplate fixation for the standard and small glenoid baseplates, respectively. For standard baseplates, the average displacement with 2 screws was significantly greater than that with 4 screws in both the AP (before cyclic loading, $P < .0001$; after cyclic loading, $P < .0001$) and SI (before cyclic loading, $P = .0036$; after cyclic loading, $P = .0414$) directions and was significantly greater than that with 6 screws in the AP direction before ($P = .0017$) and after ($P = .0002$) cyclic loading. In addition, with standard baseplates, no differences were observed in displacement before and after cyclic loading between the 4- and 6-screw configurations in either the SI or AP direction (Table I). For small baseplates, after cyclic loading, the average displacement with 2 screws was significantly greater than that with 4 screws in the AP direction ($P = .0070$), and the difference in displacement before and after cyclic loading with 2 screws was significantly greater than that with 4 screws in both the SI ($P = .0025$) and AP ($P < .0001$) directions (Table II).

Tables III and IV describe the impact of screw length on baseplate fixation for the standard and small glenoid baseplates, respectively. For standard baseplates, the average displacement with 18-mm screws was significantly greater than that with 46-mm screws in the AP (before cyclic loading, $P = .0016$; after cyclic loading, $P = .0497$) and SI (before cyclic loading, $P = .0001$; after cyclic loading, $P < .0001$) directions and was significantly greater than that with 30-mm screws in the AP direction before ($P = .0412$) and after ($P = .0166$) cyclic loading, as well as in the SI direction after cyclic loading ($P = .0198$). In addition, with standard baseplates, the average displacement with 30-mm screws was significantly greater than that with 46-mm screws in the SI direction before ($P = .0120$) and after ($P = .0015$) cyclic loading (Table III). For small baseplates, the average displacement with 18-mm screws was significantly greater than that with 30-mm screws before and after cyclic loading in the AP ($P < .0001$ and $P = .0005$, respectively) and SI ($P < .0001$ and $P = .0002$, respectively) directions. Similarly, the average displacement with 18-mm screws was significantly greater than that with 46-mm screws before and after cyclic loading in the AP ($P < .0001$ and $P < .0001$, respectively) and SI ($P < .0001$ and $P < .0001$, respectively) directions (Table IV). Finally,
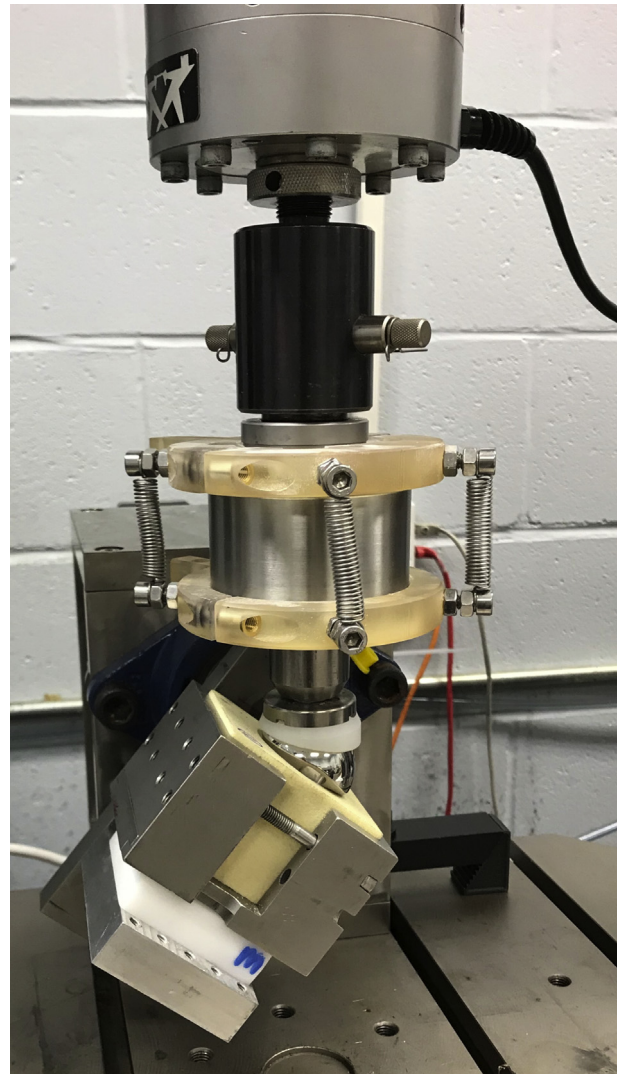

Figure 5 Cyclic test, in which a 750-N load is applied through the humeral liner as the glenoid component is cycled about an arc of 55° at 0.5 Hz for 10,000 cycles.

displacement after cyclic loading in both the AP and SI directions was similar for the standard and small baseplates, with no differences observed for 2 and 4 screws between baseplate sizes; the only difference observed in screw length was with 46-mm screws in SI ($P < .0001$) baseplate displacement between baseplate sizes (Table V).

Discussion

Initial glenoid fixation is critical to achieve long-term fixation in rTSA.[4,17,29] If rTSA baseplate displacement is too large, osseointegration will fail to occur. The results of this study demonstrate that for 2 different sizes of glenoid baseplates, initial fixation is impacted by both the quantity of screws and the length of screws used to obtain initial fixation. Regardless of the quantity of screws used, the use of longer screws was associated with significantly better fixation before and after cyclic loading. In addition, the use of at least 4 screws was associated with significantly better fixation irrespective of screw length, although an interesting finding was that the use of more than 4 screws showed no incremental benefit.

None of the 75 tested devices catastrophically failed in this low-density bone-substitute model, demonstrating that adequate

Table I
Impact of screw quantity on rTSA glenoid baseplate displacement before and after cyclic loading of standard glenoid baseplate in 24-g/cm^3 bone-substitute substrate

	SI			AP		
	Shear Pre	Shear Post	Post-Pre displacement	Shear Pre	Shear Post	Post-Pre displacement
Average standard-baseplate shear displacement, μm						
2 screws	116 ± 36	125 ± 44	10 ± 26	227 ± 80	275 ± 94	48 ± 75
4 screws	82 ± 22	91 ± 23	9 ± 13	114 ± 33	129 ± 35	15 ± 12
6 screws	92 ± 20	108 ± 42	16 ± 25	146 ± 59	160 ± 73	14 ± 28
P value						
ANOVA	.0042*	.0489*	.6667	<.0001*	<.0001*	.0928
2 screws vs. 4 screws	.0036*	.0414*	—	<.0001*	<.0001*	—
2 screws vs. 6 screws	.0545	.2751	—	.0017*	.0002*	—
4 screws vs. 6 screws	.1841	.1817	—	.3269	.4840	—

rTSA, reverse total shoulder arthroplasty; *SI*, superior-inferior; *AP*, anterior-posterior; *Pre*, before cyclic loading; *Post*, after cyclic loading; *ANOVA*, analysis of variance.
* Statistically significant ($P < .05$).

fixation can be achieved with as few as two 4.5 × 18—mm screws for the 2 baseplate designs used in this low-density glenoid loosening model. Previous testing using the same ASTM 2028 glenoid loosening method in a low-density polyurethane model has shown that multiple different commercially marketed rTSA baseplate designs have catastrophically loosened, in which loosening during the cyclic test typically occurred for designs associated with average baseplate displacement before cyclic loading in both the SI and AP directions greater than 225 μm.[35,38,39] It should be noted that none of the configurations using two 18-mm screws for either the standard or small baseplate design catastrophically loosened. However, it is noteworthy that these configurations using two 18-mm screws for both the standard and small glenoid baseplates were associated with the largest displacement before and after cyclic loading and with greater variability in fixation, with average baseplate displacement greater than 225 μm in the AP direction but not in the SI direction. Although this observed increased baseplate displacement may portend a greater risk of clinical loosening, it also suggests that better baseplate fixation in the SI direction may be more important than that in the AP direction to resist catastrophic loosening in this low-density glenoid loosening model.

Proper screw orientation is necessary to use the longest screws possible; however, the use of longer screws in the wrong orientation can be potentially hazardous. Molony et al[25] performed a cadaveric study with the Grammont reverse shoulder to analyze screw placement and reported that 40% of both superior and posterior glenoid baseplate screws can contact a branch of the suprascapular nerve. Hart et al[11] performed a similar cadaveric study with the DJO RSP reverse shoulder (DJO, LLC, Dallas, TX, USA) and reported that 5 of 10 superior screws violated the subscapularis muscle belly and 3 of 10 posterior screws contacted the suprascapular nerve or artery. Similarly, Humphrey et al[14] performed a cadaveric study analyzing screw orientation using both fixed-angle and variable-angle baseplates and reported that 4 of 10 fixed-angle baseplates positioned the superior screw near the suprascapular

nerve compared with 0 of 10 variable-angle baseplates. In addition to variable-angle baseplates, new technologies are available to improve rTSA screw positioning and/or length, including 3-dimensional preoperative planning,[15,19,26] patient-specific glenoid instruments,[12,23,41,42] and intraoperative computer navigation.[6,21,26,40,42] If used correctly, these new technologies can also ensure screw placement in the "scapular safe zone" as described by Shishido and Kikuchi[36] to avoid the suprascapular nerve and artery. Furthermore, scapular insufficiency fractures have previously been shown to sometimes propagate from the superior and/or posterior screw tip.[5,20,28] As a result, better control and visualization of screw orientation may offer the potential to avoid the aforementioned hazards when attempting to use the longest screws possible to obtain fixation in rTSA.

If the use of 4 screws is not feasible in any particular case, our results show that the use of longer screws may be an adequate substitute. Hoenig et al[13] performed a cadaveric study evaluating the impact on fixation when no posterior glenoid screw was used compared with when a short or long posterior screw was used. They found that 4 screws were associated with better fixation than 3 screws and the use of a longer posterior screw was associated with better fixation than the use of a shorter posterior screw. Their results align well with our findings. Conversely, James et al[16] performed a cadaveric study that quantified the initial fixation associated with baseplates having 2 and 4 screws up to 300 cycles. They reported no difference in displacement between baseplates with 2 and 4 screws and concluded that only 2 screws were necessary. The contradictory findings between the study of James et al and our study are best explained by the differences in testing methodology. As described previously by Friedman,[9] James et al only tested up to 300 cycles and used a non-physiological loading method, and their study was statistically underpowered. In our study, we found that the use of more than 4 screws was not necessary as the use of up to 6 screws demonstrated no incremental benefit to fixation after cyclic loading using the ASTM 2028 methodology. This finding

Table II
Impact of screw quantity on rTSA glenoid baseplate displacement before and after cyclic loading of small glenoid baseplate in 24-g/cm^3 bone-substitute substrate

	SI			AP		
	Shear Pre	Shear Post	Post-Pre displacement	Shear Pre	Shear Post	Post-Pre displacement
Average small-baseplate shear displacement, μm						
2 screws	93 ± 21	118 ± 33	25 ± 17	197 ± 87	244 ± 93	47 ± 34
4 screws	97 ± 12	104 ± 22	7 ± 12	160 ± 57	162 ± 57	2 ± 13
P value for 2 screws vs. 4 screws	.5379	.1871	.0025*	.1788	.0070*	<.0001*

rTSA, reverse total shoulder arthroplasty; *SI*, superior-inferior; *AP*, anterior-posterior; *Pre*, before cyclic loading; *Post*, after cyclic loading.
* Statistically significant ($P < .05$).

Table III
Impact of screw length on rTSA glenoid baseplate displacement before and after cyclic loading of standard glenoid baseplate in 24-g/cm^3 bone-substitute substrate

	SI			AP		
	Shear Pre	Shear Post	Post-Pre displacement	Shear Pre	Shear Post	Post-Pre displacement
Average standard-baseplate shear displacement, μm						
18-mm screws	115 ± 39	140 ± 45	25 ± 29	213 ± 102	240 ± 105	26 ± 30
30-mm screws	101 ± 12	111 ± 16	11 ± 14	152 ± 35	164 ± 47	12 ± 13
46-mm screws	74 ± 15	73 ± 8	−1 ± 10	122 ± 44	160 ± 104	39 ± 77
P value						
ANOVA	.0001*	<.0001*	.0032*	.0019*	.0315*	.3422
18 mm vs. 30 mm	.2536	.0198*	.1193	.0412*	.0166*	—
18 mm vs. 46 mm	.0001*	<.0001*	.0022*	.0016*	.0497*	—
30 mm vs. 46 mm	.0120*	.0015*	.2530	.4445	.9921	—

rTSA, reverse total shoulder arthroplasty; SI, superior-inferior; AP, anterior-posterior; Pre, before cyclic loading; Post, after cyclic loading; ANOVA, analysis of variance.
* Statistically significant ($P < .05$).

offers the potential for both a shorter surgical time and cost savings and may reduce the occurrence of other complications, such as scapular fractures[5,20,28] or suprascapular nerve injury.[11,14,25,44]

This study has several limitations. First, it is a biomechanical analysis using only 2 glenoid baseplates in a low-density polyurethane block. Although polyurethane blocks are ideal for their consistency, they differ in character from cadaveric scapular bone. As the substrate was of uniform density, we were unable to simulate bicortical fixation, which is biomechanically advantageous for fixation[11,13,14]; as such, the uniform low-density substrate used in our study represents the worst-case condition simulating poor-quality cancellous bone without bicortical fixation. Thus, the observed fixation of the tested devices in these low-density blocks is substantially higher than what would be expected if a higher-density substrate were used. The uniform 24-g/cm^3 density of the polyurethane block best facilitated a direct comparison between all 75 test specimens as this lower density would emphasize the differences in test variables. Furthermore, the use of a composite scapula was considered but decided against as the use of longer screws would inevitably have resulted in bicortical fixation in some baseplate screw positions, whereas shorter screws in the same position would have only achieved unicortical fixation. In addition, it has been demonstrated that scapular or glenoid deformity and/or anatomic morphologic variations can impact rTSA glenoid fixation.[7,8,33-35] As we did not attempt to simulate any glenoid defect in our study, care should be taken when extrapolating our recommendations to the clinical condition when an rTSA is used with a significant glenoid defect. Furthermore, all baseplates used in this study had full backside support. We did not attempt to identify the impact of screw length or screw quantity when the baseplate was only partially supported. Moreover, all tested glenoid baseplates of each configuration had poly-axial locking compression screws; therefore, we did not evaluate the impact on fixation of locking screws or compression screws independently as some devices on the market use either locking screws or compression screws. Finally, these recommendations may not be applicable to other rTSA prosthesis designs as the 30 × 24−mm small baseplate and the 34 × 25−mm standard baseplate used in this study have large surface areas relative to other designs.[27,31] However, it is interesting that the findings related to the independent contribution of screw length and screw quantity to fixation were similar despite the differences in design and surface area between the standard and small baseplates; this suggests that our study findings may be generalizable, which the reader can extrapolate to other glenoid baseplate styles available in the marketplace. Future work should evaluate the impact of both screw length and screw quantity for multiple different prostheses of even smaller surface areas in different densities of bone with and without glenoid defects to further generalize our screw length recommendations.

Conclusion

Both the quantity of screws and the length of screws used in reverse shoulder arthroplasty have an impact on glenoid fixation, regardless of glenoid baseplate size. Using longer screws and more screws when securing the rTSA glenoid baseplate was shown to improve fixation in this low-density glenoid loosening model. If the use of more than 2 screws is not feasible, then the orthopedic surgeon can use longer screws as a substitute to achieve greater baseplate fixation. Finally, the use of more than 4 screws showed no incremental benefit in fixation and therefore may not be necessary unless there is a significant glenoid defect.

Table IV
Impact of screw length on rTSA glenoid baseplate displacement before and after cyclic loading of small glenoid baseplate in 24-g/cm^3 bone-substitute substrate

	SI			AP		
	Shear Pre	Shear Post	Post-Pre displacement	Shear Pre	Shear Post	Post-Pre displacement
Average small-baseplate shear displacement, μm						
18-mm screws	115 ± 8	141 ± 28	26 ± 22	270 ± 51	291 ± 74	20 ± 31
30-mm screws	89 ± 6	102 ± 12	13 ± 11	136 ± 27	174 ± 70	38 ± 47
46-mm screws	81 ± 10	89 ± 9	8 ± 12	128 ± 23	143 ± 22	16 ± 17
P value						
ANOVA	<.0001*	<.0001*	.0497*	<.0001*	<.0001*	.3252
18 mm vs. 30 mm	<.0001*	.0002*	.1970	<.0001*	.0005*	—
18 mm vs. 46 mm	<.0001*	<.0001*	.0465*	<.0001*	<.0001*	—
30 mm vs. 46 mm	.0983	.2810	.7431	.8466	.4946	—

rTSA, reverse total shoulder arthroplasty; SI, superior-inferior; AP, anterior-posterior; Pre, before cyclic loading; Post, after cyclic loading; ANOVA, analysis of variance.
* Statistically significant ($P < .05$).

Table V
Comparison of SI and AP baseplate displacement after cyclic loading between the standard and small glenoid baseplates in a 24-g/cm^3 bone substitute substrate

| | Baseplate shear displacement, μm | | | | | |
| | SI | | | AP | | |
	Standard baseplate	Small baseplate	P value	Standard baseplate	Small baseplate	P value
2 screws	125 ± 44	118 ± 33	.5889	275 ± 94	244 ± 93	.3648
4 screws	91 ± 23	104 ± 22	.1359	129 ± 35	162 ± 57	.0728
18-mm screws	140 ± 45	141 ± 28	.9793	240 ± 105	291 ± 74	.1964
30-mm screws	111 ± 16	102 ± 12	.1345	164 ± 47	174 ± 70	.6745
46-mm screws	73 ± 8	89 ± 9	<.0001[*]	160 ± 104	143 ± 22	.6173

SI, superior-inferior; *AP*, anterior-posterior.

[*] Statistically significant (*P* < .05).

Disclaimer

References

1. Anglin C, Tolhurst P, Wyss UP, Pichora DR. Glenoid cancellous bone strength and modulus. J Biomech 1999;32:1091–7.
2. ASTM International: ASTM F 1839-08: standard specification for rigid polyurethane foam for use as a standard material for testing orthopaedic devices and instruments. Available at: https://www.astm.org/Standards/F1839.htm; 2012.
3. ASTM International: ASTM F 2028-17: standard test methods for dynamic evaluation of glenoid loosening or disassociation. West Conshohocken, PA: ASTM International; 2017.
4. Cameron HU, Pilliar RM, MacNab I. The effect of movement on the bonding of porous metal to bone. J Biomed Mater Res 1973;7:301–11.
5. Crosby LA, Hamilton A, Twiss T. Scapula fractures after reverse total shoulder arthroplasty: classification and treatment. Clin Orthop Relat Res 2011;469: 2544–9. https://doi.org/10.1007/s11999-011-1881-3.
6. Edwards TB, Gartsman GM, O'Connor DP, Sarin VK. Safety and utility of computer-aided shoulder arthroplasty. J Shoulder Elbow Surg 2008;17:503–8. https://doi.org/10.1016/j.jse.2007.10.005.
7. Formaini NT, Everding NG, Levy JC, Santoni BG, Nayak AN, Wilson C, et al. The effect of glenoid bone loss on reverse shoulder arthroplasty baseplate fixation. J Shoulder Elbow Surg 2015;24:e312–9. https://doi.org/10.1016/j.jse.2015.05.045.
8. Frankle MA, Teramoto A, Luo Z-P, Levy JC, Pupello D. Glenoid morphology in reverse shoulder arthroplasty: classification and surgical implications. J Shoulder Elbow Surg 2009;18:874–85. https://doi.org/10.1016/j.jse.2009.02.013.
9. Friedman RJ. Reverse shoulder arthroplasty glenoid fixation. J Shoulder Elbow Surg 2014;23:e91. https://doi.org/10.1016/j.jse.2013.12.024.
10. Guery J, Favard L, Sirveaux F, Oudet D, Mole D, Walch G. Reverse total shoulder arthroplasty. Survivorship analysis of eighty replacements followed for five to ten years. J Bone Joint Surg Am 2006;88:1742–7. https://doi.org/10.2106/JBJS.E.00851.
11. Hart ND, Clark JC, Wade Krause FR, Kissenberth MJ, Bragg WE, Hawkins RJ. Glenoid screw position in the Encore Reverse Shoulder Prosthesis: an anatomic dissection study of screw relationship to surrounding structures. J Shoulder Elbow Surg 2013;22:814–20. https://doi.org/10.1016/j.jse.2012.08.013.
12. Hendel MD, Bryan JA, Barsoum WK, Rodriguez EJ, Brems JJ, Evans PJ, et al. Comparison of patient-specific instruments with standard surgical instruments in determining glenoid component position: a randomized prospective clinical trial. J Bone Joint Surg Am 2012;94:2167–75. https://doi.org/10.2106/JBJS.K.01209.
13. Hoenig MP, Loeffler B, Brown S, Peindl R, Fleischli J, Connor P, et al. Reverse glenoid component fixation: is a posterior screw necessary? J Shoulder Elbow Surg 2010;19:544–9. https://doi.org/10.1016/j.jse.2009.10.006.
14. Humphrey CS, Kelly JD II, Norris TR. Optimizing glenosphere position and fixation in reverse shoulder arthroplasty, part two: the three-column concept. J Shoulder Elbow Surg 2008;17:595–601. https://doi.org/10.1016/j.jse.2008.05.038.
15. Jacquot A, Gauci MO, Chaoui J, Baba M, Deransart P, Boileau P, et al. Proper benefit of a three dimensional pre-operative planning software for glenoid component positioning in total shoulder arthroplasty. Int Orthop 2018;42: 2897–906. https://doi.org/10.1007/s00264-018-4037-1.
16. James J, Allison MA, Werner FW, McBride DE, Basu NN, Sutton LG, et al. Reverse shoulder arthroplasty glenoid fixation: is there a benefit in using four instead of two screws? J Shoulder Elbow Surg 2013;22:1030–6. https://doi.org/10.1016/j.jse.2012.11.006.
17. Jasty M, Bragdon C, Burke D, O'Connor D, Lowenstein J, Harris WH. In vivo skeletal responses to porous-surfaced implants subjected to small induced motions. J Bone Joint Surg Am 1997;79:707–14.
18. Kalouche I, Crépin J, Abdelmoumen S, Mitton D, Guillot G, Gagey O. Mechanical properties of glenoid cancellous bone. Clin Biomech (Bristol, Avon) 2010;25: 292–8. https://doi.org/10.1016/j.clinbiomech.2009.12.009.
19. Kelly JD II, Humphrey CS, Norris TR. Optimizing glenosphere position and fixation in reverse shoulder arthroplasty, part one: the twelve-mm rule. J Shoulder Elbow Surg 2008;17:589–94. https://doi.org/10.1016/j.jse.2007.08.013.
20. Kennon JC, Lu C, McGee-Lawrence ME, Crosby LA. Scapula fracture incidence in reverse total shoulder arthroplasty using screws above or below metaglene central cage: clinical and biomechanical outcomes. J Shoulder Elbow Surg 2017;26:1023–30. https://doi.org/10.1016/j.jse.2016.10.018.
21. Kircher J, Wiedemann M, Magosch P, Lichtenberg S, Habermeyer P. Improved accuracy of glenoid positioning in total shoulder arthroplasty with intraoperative navigation: a prospective-randomized clinical study. J Shoulder Elbow Surg 2009;18:515–20. https://doi.org/10.1016/j.jse.2009.03.014.
22. Lehtinen JT, Tingart MJ, Apreleva M, Warner JJP. Total, trabecular, and cortical bone mineral density in different regions of the glenoid. J Shoulder Elbow Surg 2004;13:344–8. https://doi.org/10.1016/j.jse.2004.01.012.
23. Levy JC, Everding NG, Frankle MA, Keppler LJ. Accuracy of patient-specific guided glenoid baseplate positioning for reverse shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1563–7. https://doi.org/10.1016/j.jse.2014.01.051.
24. Mimar R, Limb D, Hall RM. Evaluation of the mechanical and architectural properties of glenoid bone. J Shoulder Elbow Surg 2008;17:336–41. https://doi.org/10.1016/j.jse.2007.07.024.
25. Molony DC, Cassar Gheiti AJ, Kennedy J, Green C, Schepens A, Mullett HJ. A cadaveric model for suprascapular nerve injury during glenoid component screw insertion in reverse-geometry shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:1323–7. https://doi.org/10.1016/j.jse.2011.02.014.
26. Nguyen D, Ferreira LM, Brownhill JR, King GJ, Drosdowech DS, Faber KJ, et al. Improved accuracy of computer assisted glenoid implantation in total shoulder arthroplasty: an in-vitro randomized controlled trial. J Shoulder Elbow Surg 2009;18:907–14. https://doi.org/10.1016/j.jse.2009.02.022.
27. Nigro PT, Gutiérrez S, Frankle MA. Improving glenoid-side load sharing in a virtual reverse shoulder arthroplasty model. J Shoulder Elbow Surg 2013;22: 954–62. https://doi.org/10.1016/j.jse.2012.10.025.
28. Otto RJ, Virani NA, Levy JC, Nigro PT, Cuff DJ, Frankle MA. Scapular fractures after reverse shoulder arthroplasty: evaluation of risk factors and the reliability of a proposed classification. J Shoulder Elbow Surg 2013;22:1514–21. https://doi.org/10.1016/j.jse.2013.02.007.
29. Pilliar RM, Lee JM, Maniatopoulos C. Observations on the effect of movement on bone ingrowth into porous-surfaced implants. Clin Orthop Relat Res 1986: 108–13.
30. Roche C, Flurin PH, Wright T, Crosby LA, Hutchinson D, Zuckerman JD. Effect of varying screw configuration and bone density on reverse shoulder glenoid fixation following cyclic loading. In: Transactions of the annual meeting of the Orthopaedic Research Society. San Francisco, CA: Orthopaedic Research Society; 2008. p. 1553.
31. Roche CP, Diep P, Hamilton MA, Flurin PH, Routman HD. Comparison of bone removed with reverse total shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):S36–40.
32. Roche CP, Stroud NJ, Flurin PH, Wright TW, Zuckerman JD, DiPaola MJ. Reverse shoulder glenoid baseplate fixation: a comparison of flat-back versus curved-back designs and oval versus circular designs with 2 different offset glenospheres. J Shoulder Elbow Surg 2014;23:1388–94. https://doi.org/10.1016/j.jse.2014.01.050.

33. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin PH, Wright TW, et al. The impact of scapular notching on reverse shoulder glenoid fixation. J Shoulder Elbow Surg 2013;22:963–70. https://doi.org/10.1016/j.jse.2012.10.035.

34. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin PH, Wright TW, et al. Achieving fixation in glenoids with superior wear using reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:1695–701. https://doi.org/10.1016/j.jse.2013.03.008.

35. Roche CP, Stroud NJ, Palomino P, Flurin PH, Wright TW, Zuckerman JD, et al. The impact of anterior glenoid defects on reverse shoulder glenoid fixation in a composite scapula model. Bull Hosp Jt Dis (2013) 2018;76:116–22.

36. Shishido H, Kikuchi S. Injury of the suprascapular nerve in shoulder surgery: an anatomic study. J Shoulder Elbow Surg 2001;10:372–6.

37. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388–95. https://doi.org/10.1302/0301-620X.86B3.14024.

38. Stroud N, DiPaola MJ, Flurin PH, Roche CP. Reverse shoulder glenoid loosening: an evaluation of the initial fixation associated with six different reverse shoulder designs. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):S12–7.

39. Stroud NJ, DiPaola MJ, Martin BL, Steiler CA, Flurin PH, Wright TW, et al. Initial glenoid fixation using two different reverse shoulder designs with an equivalent center of rotation in a low-density and high-density bone substitute. J Shoulder Elbow Surg 2013;22:1573–9. https://doi.org/10.1016/j.jse.2013.01.037.

40. Verborgt O, De Smedt T, Vanhees M, Clockaerts S, Parizel PM, Van Glabbeek F. Accuracy of placement of the glenoid component in reversed shoulder arthroplasty with and without navigation. J Shoulder Elbow Surg 2011;20:21–6. https://doi.org/10.1016/j.jse.2010.07.014.

41. Verborgt O, Hachem AI, Eid K, Vuylsteke K, Ferrand M, Hardy P. Accuracy of patient-specific guided implantation of the glenoid component in reversed shoulder arthroplasty. Orthop Traumatol Surg Res 2018;104:767–72. https://doi.org/10.1016/j.otsr.2018.01.010.

42. Verborgt O, Vanhees M, Heylen S, Hardy P, Declercq G, Bicknell R. Computer navigation and patient-specific instrumentation in shoulder arthroplasty. Sports Med Arthrosc Rev 2014;22:e42–9. https://doi.org/10.1097/JSA.0000000000000045.

43. Werner CML, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476–86. https://doi.org/10.2106/JBJS.D.02342.

44. Yang Y, Zuo J, Liu T, Shao P, Wu H, Gao Z, et al. Glenoid morphology and the safe zone for protecting the suprascapular nerve during baseplate fixation in reverse shoulder arthroplasty. Int Orthop 2018;42:587–93. https://doi.org/10.1007/s00264-017-3646-4.

45. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146–57. https://doi.org/10.1016/j.jse.2010.08.001.