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Correlation of preoperatively planned humeral component size and actual implanted size: a retrospective and prospective evaluation of anatomic and reverse shoulder arthroplasty

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Background: The aims of the study were to (1) evaluate the correlation of planned humeral component diameter with implanted humeral component diameter for reverse total shoulder arthroplasty (rTSA) and (2) to evaluate the correlation of planned humeral components with executed humeral components for stemless anatomic TSA.

Methods: Four shoulder surgeons participated in two phases of the study. In the retrospective arm, 3 months of TSA and rTSA cases which were completed with preoperative computed tomography-based planning, but without any humeral planning, were replanned using humeral planning, and the components from the virtual planning compared to the implanted components. In the prospective arm, 3 months of TSA and rTSA cases were prospectively planned by each surgeon. The planned and implanted components were similarly compared.

Results: Ninety-seven rTSAs were included (50 retrospective, 48 prospective). In the retrospective analysis, in 60% of cases, the rTSA stem diameter was within one size of the plan; in 84%, it was within two sizes; in 90%, it was within 3 sizes. In the prospective analysis, the rTSA stem diameter was within one size in 73% of cases; in 90% within 2 sizes, and in 94% within 3 sizes ($P > .05$ all comparisons). The cup diameter was always within one size of the plan; it matched in 84% of the retrospective cases and 90% of the prospective cases ($P > .05$). Seventy-seven TSAs were included (33 retrospective, 44 prospective). For prosthetic head diameter, in the retrospective analysis, it was an exact match in 52% of patients, within one size in 85% and within two sizes in 100%. In the prospective analysis, the diameter was an exact match in 57%, within one size in 86% and within two sizes in 100% ($P > .05$ all comparisons). The thickness of the prosthetic component was a match to the plan in 88% of the retrospective cases and 86% of prospective cases ($P > .05$).

Conclusion: For the utilized planning software and implants, humeral planning for rTSA affords some predictability for stem diameter regardless of whether assessed retrospectively or prospectively, with 84%-90% of cases within two diameters of the plan. The inlay humeral cup diameter was an exact match to the plan in 84%-90% of cases. For stemless anatomic TSA, the humeral component diameter was an exact match to the plan in 52%-57%, but within one size in 85%-86% of cases. There were no significant differences if the planning was performed retrospectively or prospectively.

Preoperative computed tomography (CT)-based three-dimensional planning has become an increasingly important tool for shoulder arthroplasty surgeons. Though the specific details and supporting research vary between industry partners, there are numerous generally accepted benefits of CT-based planning, including improved recognition and management of glenoid deformity,[4] assistance in decision-making between anatomic and reverse arthroplasty when significant glenoid deformity or

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This work was performed at the University of Virginia.

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posterior humeral subluxation are present,[13,14] and more precise selection and positioning of both anatomic and reverse glenoid components.[5,6,8]

Although the primary focus of preoperative planning for shoulder arthroplasty has been on the glenoid, there has been growing interest in humeral planning. Particularly for anatomic total shoulder arthroplasty (aTSA), there is increasing recognition of the importance of an accurate humeral reconstruction and restoration of the ideal center of rotation and the frequent failure to do so surgically.[2,10,12] For reverse total shoulder arthroplasty (rTSA), humeral planning could potentially additionally identify deformities and allow for range of motion simulations. For both TSA and rTSA, humeral planning, if accurate, could allow for a more seamless transition to ambulatory surgical environments, where inventory management and cost containment are even more paramount.

The clinical literature surrounding the reliability of humeral planning in predicting the implanted components is limited, variable in conclusions, and requires analyses across each individual platform to assure validity. Recent retrospective clinical investigations have demonstrated variability in the correlation between implanted and preoperatively planned humeral stem diameter, humeral component diameter and thickness and humeral neck shaft angle.[3,7,9,11] Given the variability in findings of previous studies and lack of prospective data investigating the correlation between planned and implanted humeral components, the primary goal of this study was to investigate in both a retrospective and prospective design (1) the correlation of planned humeral component diameter with implanted humeral component diameter for rTSA and (2) to evaluate the correlation of planned humeral components with executed humeral components for stemless aTSA. We hypothesized that there would be good correlation between the planned and implanted components and that there would be no difference in this correlation between the prospective and retrospective analyses, indicating that knowledge of the plan intraoperatively did not influence the surgeon's decision to use a planned component.

Materials and methods

Surgeons and patients

Institutional review board approval was obtained prior to beginning the study. Four fellowship-trained shoulder surgeons who perform over 50 shoulder arthroplasties annually participated in the study. All participating surgeons were familiar with the preoperative planning software utilized in the study and utilized it in their clinical practices. There was both a retrospective and clinical arm to the study. The retrospective arm was completed prior to beginning the prospective arm.

All preoperative planning was performed using the Virtual Implant Positioning (VIP; Arthrex Inc., Naples, FL, USA). All surgeons planned and clinically utilized the same implants: for rTSA, an inlay humerus with 135° NSA (Univers or Apex; Arthrex Inc., Naples, FL, USA); for TSA, a stemless component with a cage screw (Eclipse; Arthrex Inc., Naples, FL, USA). For rTSA, three variables were compared: stem diameter, inlay cup diameter, and cup offset. For TSA, three variables were compared: prosthetic head diameter, prosthetic head thickness (anatomic or extended), and cage screw length.

In the retrospective arm, three months of TSA and rTSA cases for each surgeon which were completed with preoperative CT-based planning, but without any humeral planning, were replanned utilizing humeral planning. Enrollment was competitive, but a minimum of 10 TSA/rTSA cases per surgeon was required. The surgeons were blinded to the implanted components when performing the planning. The components from the retrospective virtual planning were then compared to the clinically implanted components. In the prospective arm, 3 months of TSA and rTSA cases were prospectively planned by each surgeon. Enrollment in this arm was also competitive, but a minimum of 10 TSA/rTSA cases per surgeon was required. Different from the retrospective arm, the surgeon had the humeral planning information available intraoperatively. The planned and implanted components were similarly compared.

Outcomes and statistical analyses

The primary outcome was the correlation of the implanted component with the planned component. For each prospective or retrospective comparison, the percentages of exact matches (all variables), and then percentages of each deviation from an exact match (+/− stem or head diameter, deviation in head thickness, or cage screw size) were calculated and compared.

Statistical analysis

All statistical analyses were performed in SPSS, Version 28 (IBM Corp., Armonk, NY, USA). Comparisons of percentages were made with chi-squared analyses. For all comparisons, $P < .05$ was considered statistically significant.

Results

Reverse shoulder arthroplasty

Ninety-eight rTSAs were included (50 retrospective, 48 prospective). In the retrospective analysis, in 22% of cases, the stem diameter was an exact match; in 60% of cases, the stem diameter was within one size of the plan; in 84% of cases, it was within two sizes; in 90% of cases, it was within 3 sizes. In the prospective analysis, the stem diameter was an exact match in 38% of cases ($P = .093$ compared to retrospective); within one size of the plan in 73% of cases ($P = .176$ compared to retrospective); within 2 sizes in 90% of cases ($P = .415$ compared to retrospective), and within 3 sizes in 94% of cases ($P = .498$ compared to retrospective). The cup diameter was always within one size of the plan; it was an exact match in 84% of the retrospective cases and 90% of the prospective cases ($P = .372$). Cup offset was an exact match in 44% of retrospective cases and 66% of prospective cases ($P = .027$) (Table I).

Total shoulder arthroplasty

Seventy-seven TSAs were included (33 retrospective, 44 prospective). In the retrospective analysis, the prosthetic head diameter was an exact match to the plan in 52% of patients, within one size in 85% and within two sizes in 100%. In the prospective analysis, the diameter was an exact match in 57% of cases ($P = .644$ compared to retrospective), within one size in 86% ($P = .851$ compared to retrospective) and within two sizes in 100% ($P = 1.000$ compared to retrospective). The thickness of the prosthetic component was a match to the plan in 88% of the retrospective cases and 86% of prospective cases ($P = .845$). In the retrospective analysis, the cage screw length was an exact match in 64% of cases and within one size in 100% of cases; in the prospective analysis, the cage screw was an exact match in 77% of cases ($P = .190$) and within one size in 100% of cases ($P = 1.000$) (Table I).

Discussion

There were several important findings of this investigation. For the studied preoperative planning implants and software, humeral

Table I
Comparative results of retrospective and prospective analyses.

	Parameter	Match	Retrospective	Prospective	*P*
Reverse TSA	Stem diameter	Exact match	22%	38%	.093
		+/− 1 size	60%	73%	.176
		+/− 2 sizes	84%	90%	.415
		+/− 3 sizes	100%	94%	.498
	Cup diameter	Exact match	84%	90%	.372
		+/− 1 size	100%	100%	1.000
	Cup offset	Exact match	44%	66%	.027
Stemless TSA	Prosthetic head diameter	Exact match	52%	57%	.644
		+/− 1 size	85%	86%	.851
		+/− 2 sizes	100%	100%	1.000
	Head thickness	Exact match	88%	86%	.845
	Cage screw length	Exact match	64%	77%	.190
		+/− 1 size	100%	100%	1.000

TSA, total shoulder arthroplasty.

planning affords some predictably for rTSA stem diameter. Although exact matches to the humeral plan were infrequent, 84%-90% of cases were within two diameters of the planned stem diameter. The inlay humeral cup was frequently an exact match. For stemless aTSA using the same planning software, the humeral component diameter was an exact match in about 50% of cases; but within one diameter in 85% of cases.

One previous retrospective study has examined concordance of planned and implanted humeral components for rTSA for a different implant system and software. Wittman et al retrospectively evaluated 129 patients, including 117 rTSA, and compared planned with final implanted stem size, stem inclination, tray-offset, and liner-thickness.[15] The concordance of planned to implanted stem size was low at 44%, which is similar to the rate of exact concordance in our evaluation, which ranged from 22% to 38%. The planned size was within one diameter of the implanted stem in 88% of cases, which was similar, but slightly higher than the 60%-73% of cases in our evaluation. The authors reported that tray offset in rTSA was predicted correctly in 65% of cases, which is similar to the 66% rate of concordance observed in the prospective arm of our evaluation. Overall, the authors reached similar conclusions to our investigation, with a different implant system and software, demonstrating that despite a low degree of exact concordance of stem size, the stem size is frequently within 1-2 adjacent sizes, highlighting the potential value of humeral planning in rTSA for reduction of inventory and perhaps reducing surgical steps. Additional investigation is needed to understand what surgeon and patient factors lead to alterations from the preoperative plan to improve the accuracy of predicting humeral implants for rTSA. One potential explanation is the inability for current planning software to assess cortical and cancellous bone quality. Variability in bone quality can contribute significantly to humeral press fit and therefore sizing.

There is more literature examining the concordance of humeral planning with implanted components for aTSA. Baumgarten reported on 307 aTSA, of which 116 patients (38%) had an intraoperative change to their humeral plan.[1] The most frequent deviations from the humeral plan were a change in humeral head thickness (n = 78, 67% of deviations) or change in humeral diameter (n = 64, 55% of deviations). Patients who had intraoperative changes to their preoperative plan had inferior postoperative outcome scores and larger deviations in the postoperative radiographic restoration of the humeral center of rotation, indicating the potential consequences of deviating from a preoperative plan and the potential benefits of humeral planning for aTSA.[1] Freehill et al retrospectively evaluated 111 aTSAs, of which 87 (78%) were stemless prostheses. Seventy-nine percent of patients matched their preoperative plan exactly, and 98% were within one size.[3] Finally, in another retrospective evaluation, Rechenmacher and coauthors evaluated concordance between implanted and planned components on 50 patients who underwent stemless aTSA.[9] Planned humeral head implants were more often oversized relative to their actual implanted size. Similar to the present investigation, however, 84% of the planned humeral heads were within one diameter of the size of the implanted prosthesis.[9] It is clear from the present investigation and these additional studies that while there is some reasonable concordance between planned and implanted aTSA humeral components, there remains additional work that must be completed to improve accuracy, and larger studies may be needed to understand what surgeon and patient factors lead to deviations from planned. Regardless, the findings of this study support that humeral planning for aTSA can at a minimum provide an intraoperative starting point for sizes and is reasonably accurate to within one humeral diameter.

An interesting aspect of the present analysis was the ability to examine whether intraoperative knowledge of the humeral plan had any association with the concordance of planned to implanted components. Contrary to our hypothesis, with the exception of cup offset, there were no significant differences in concordance for rTSA or TSA. This would suggest that knowledge of the plan does not influence how a surgeon chooses their implants; rather, the rates of concordance are due to other factors, such as accuracy of the software and surgeon preference. Despite this observed variability in concordance for both rTSA and TSA, there can still be considerable value in humeral planning not captured by this study. These include increase in surgeon confidence of execution of the procedure, and inventory reduction and the associated cost reduction, particularly in ambulatory surgery centers. Additional studies would be needed to assess the value in these areas.

There are several limitations of this study that require discussion. One significant limitation is the small sample size. While we did utilize a prospective and retrospective design, the overall sample size would need to be larger to examine additional trends or influences on concordance. Another limitation is that this study utilizes a single implant brand and commercially available software system. While this is necessary to assure consistency between surgeons and between the retrospective and prospective arms of the study, the findings of this study may not apply to other implant systems or preoperative planning software. Specific to aTSA, this study did not examine postoperative radiographic results to assess the effect of the templating on the accuracy of the humeral reconstruction. This has been studied previously by others and was therefore not a focus of this investigation. Additionally, this study purposely did not include any glenoid component analysis, which while intentional to focus on the clinical question of humeral planning, does limit the findings, as glenoid component selection for both TSA and rTSA can to some degree drive humeral component selection. Additional factors such as soft tissue balancing cannot be assessed in this study and could influence the choice of implants. Finally, this study does not include any clinical outcomes. Previous research has shown worse clinical outcomes in patients with discordance between the planned and implanted components,[1] but our study cannot examine this relationship.

Conclusion

For the utilized planning software and implants, humeral planning for rTSA affords some predictability for stem diameter regardless of whether assessed retrospectively or prospectively, with 84%-90% of cases within two diameters of the planned stem diameter. The inlay humeral cup diameter was an exact match to the plan in 84%-90% of cases. For stemless aTSA, the humeral component diameter was an exact match to the plan in 52%-57%, but within one size in 85%-86% of cases. There were no significant differences if the planning was performed retrospectively or prospectively.

Disclaimers:

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Conflicts of interest: Bradford Parsons serves as a consultant and receives royalties from Arthrex, Inc.; and serves as an editor for JBJS reviews. Brian Werner serves as a consultant and receives research support from Arthrex, Inc.; is a consultant for Lifenet; and receives research support from Biomet and Pacira. Patrick Denard serves as a consultant for Arthrex, Inc.; receives royalties and research grant from Arthrex, Inc.; and owns stock ownership in PT Genie and Kaliber Labs. The other author, his immediate family, and any research foundation with which he is affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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