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The use of preoperative planning to decrease costs and increase efficiency in the OR

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Background: Shoulder arthroplasty (SA) incurs up to $1.8B per year in societal costs. With the increasing demand for SA and the steady decrease of annual reimbursements for orthopedic procedures, it has become crucial to control costs. In SA, there has been an interest in using preoperative planning software to improve accuracy in positioning and implant selection, ultimately optimizing outcomes. However, the use of preoperative planning to increase efficiency has not been studied. The purpose of this study was to determine if preoperative planning could increase efficiency and decrease costs in the operating room.
Methods: This retrospective review included 94 patients who underwent shoulder arthroplasty and had a CT scan with a preoperative plan by a single orthopedic surgeon between 2017 and 2020. The patients were divided based on the use of the preoperative plan during surgery. Group 1 included 65 patients with a preoperative plan used during surgery, and group 2 included 29 patients without a preoperative plan utilized during surgery. Average preparation time, surgical time, time in the operating room, the number of trays sterilized, and postoperative outcomes were analyzed between the two groups. Subanalysis was done to find a statistical difference in the cost of sterilization for both groups.
Results: The cohort had 55% males, with an average age of 71 years and an average BMI of 29.9. There were no significant differences between the groups for age, BMI, or ASA class. There was no significant difference between groups in preparation time (group 1: 53.3 min, group 2: 53.1 min $P = .924$), surgical time (group 1: 119.7 min, group 2: 111.9 min; $P = .25$), or time in the OR (group 1: 183.2 min, group 2: 173.2 min; $P = .156$). There was a statistical difference in the number of trays (5 vs. 8; $P < .01$) and cost of sterilization between groups ($487.30 vs. $842.86; $P < .01$). No correlation between the number of trays and preparation time (group 1: −0.05, group 2: −0.28) or trays and surgical time was found for either group (group 1: r = −0.31, group 2: r = −0.22). There were no significant differences in postoperative outcomes between the groups.
Conclusion: While preoperative planning did not reduce time in the OR for shoulder arthroplasty, it was correlated to a significant reduction in the number and cost of sterilized trays with comparable postoperative outcomes.

With the increasing demand for shoulder arthroplasty and the steady decrease of annual reimbursements for orthopedic procedures, it has become crucial to control costs and improve efficiency.[10,18] Total shoulder arthroplasty has been shown to incur up to $1.8B per year in societal costs.[25] Insurance providers have focused on one method to provide significant cost savings through lowering average days of inpatient hospital admissions, limiting hospital stays and transition to ambulatory surgery setting for total joint replacements.[3] Interest on lowering costs now has now focused on limiting implant selection, optimizing implant pricing, and decreasing the use of hospital resources and operating room (OR) time.[16]

Careful preoperative planning can reliably measure pathology, guide intraoperative implant selection, and improve correction of pathology in shoulder arthroplasty.[17,20] In addition, three-dimensional preoperative planning software has demonstrated accuracy in predicting intraoperative implant selection in reverse shoulder arthroplasty (RSA) and total shoulder arthroplasty

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(TSA).[1,3,19,20,29] Additionally, 3D templating can potentially improve surgeon efficiency through quick and reproducible planning and reduce costs associated with bringing excess components such as surgical trays into the operating room.

Health care costs in the United States have continued to climb and represent a serious concern to societal infrastructure. Currently, the incidence of shoulder arthroplasty procedures is also increasing at a greater rate than total hip and knee arthroplasty.[28] Although limited studies have demonstrated reduced costs for templating software and template-directed instrumentation for total knee replacement,[13] studies have not shown the same cost-effectiveness of using patient-specific instrumentation shoulder arthroplasty procedures.[2] The purpose of our study is to assess how preoperative planning in SA could impact surgical efficiency and intraoperative costs. We hypothesize that, given the accuracy of preoperative planning, it can lead to decreased costs and increased efficiency in the operating room for SA.

Methods

Patient cohort

This retrospective study consisted of 94 patients that underwent either a primary total shoulder arthroplasty (TSA) or reverse shoulder arthroplasty (RSA) between 2017 and 2020 and had a 3D CT scan with a preoperative plan. Patients were split into two groups: Group 1 included patients with a 3D preoperative plan without PSI that was used during surgery to guide treatment and implant selection, and Group 2, the control group, included patients who underwent SA without the use or review of the 3D preoperative plan during surgery. Group 2 was collected from 2017 to 2018; during this time, the surgeon did not utilize the plan to guide implant selection or surgical execution. Our intervention group (group 1) had a plan that the surgeon used specifically to guide implant selection while operating; it was followed and utilized during surgery, whereas the control group had a plan that was reviewed; however, the surgeon did not use it to guide and restrict the trays or implants that were brought into the OR. All patients underwent a preoperative plan as a standard of care for this surgeon and patients in group 1 were collected from 2018 to 2020; given the published accuracy of 3D templating software[1-4,11-13] to guide addressing pathology and implant selection, the surgeons changed their practice to base the intraoperative plan and implant selection off of the preoperative planning software selections. This practice evolution was applied for all shoulder arthroplasty patients to minimize any bias in patient selection.

Preoperative planning and surgery

CT studies followed a specific standardized protocol (120 kV, 140mAs, 0.6-mm collimation, 134 512 × 512 matrix, no gantry tilt, and 50-cm field of view, fine cut) to allow for proper software modeling. Then Digital Imaging and Communications in Medicine (DICOM) files of each CT scan were uploaded into Tornier Blueprint 3D Planning (Wright Medical Inc., Memphis, TN, USA) software to preoperatively plan the surgery. Optimal image reconstruction was achieved by using a semismooth algorithm, B40, at 0.6-mm axial increments.[11] Glenoid pathology was classified in the axial plane according to the Walch classification.[22]

When planning, multiple variables were adjusted repeatedly, and only 1 preoperative plan was finalized, as the software does not allow for several saved plans to coexist on a singular patient case. On the humeral side, the humeral head cut was chosen based on the procedure performed and recommended a 132.5° angle for RSA at the optimal height of the head-neck junction. Although the epicondyles were not included in the CT scan, Blueprint is an automated program that uses specific image recognition sequences with three-dimensional landmarks to identify the scapula from the humerus and aid in the automated measurement of version and inclination.[8] The goals of planning on the glenoid side were to optimize implant seating, pathologic correction, implant sizing, and central screw fixation. In cases of severe retroversion, we employed a combination of an augmented glenoid implant and high side reaming based on standard principles to correct the pathologic version to less than 6° of retroversion and optimize greater than 90% backside seating. A Bony Increased Offset (BIO) RSA was not used in any of our cases, and all implants were from Wright medical as implants from other manufacturers were not compatible with the planning software. Glenosphere size, eccentricity, and lateralization were selected to optimize the above guidelines and passive range of motion (ROM) based on baseplate compatibility.

The patient-specific preoperative plans were reviewed and executed in Blueprint by the operating surgeon and blueprint outputs were recorded. The preoperative templated plan was used as a guide for intraoperative tray usage and implant selection for the intervention group; however, final intraoperative implant selection was always based on patient bone quality, glenohumeral anatomical size, soft tissue definition (muscle quality and muscle tension), and fit determined by the training, expertise of the senior operating surgeon. Sabesan et al. has previously validated this software's ability to reliably predict and plan intraoperative implant selection with a great degree of accuracy using the same methodology described here.[20,21]

Surgical technique

All cases were performed by single fellowship-trained shoulder surgeon at a single institution in a semi beach-chair position using a standard deltopectoral approach. The biceps tendon underwent tenodesis to the pectoral major tendon. A tenotomy of the subscapularis was made, and the subscapularis tendon and anterior capsule were released off the glenoid. The humeral head was resected respecting the native humeral head version and inclination. The humeral shaft was prepared with optimal humeral coverage for the humeral tray. The glenoid retroversion and implant placement and/or size were assessed with the 3D preoperative plan for the intervention group, and then correction and implant size final selections were made based on intraoperative surgical decision-making. Trial components were placed, and once the soft tissue tensioning and stability were trialed and tested, the final components were implanted.

Data collection

An IRB-approved prospectively collected database was retrospectively reviewed, which contained SAs performed by a single surgeon from a single academic institution. Basic demographic information was collected from electronic medical records, including, but not limited to, age, gender, body mass index (BMI), American Society of Anesthesiologists (ASA) scores, diagnosis, comorbidities, and affected side.

The database was reviewed to collect time variables from the operating room (OR), number of trays, and cost of sterilization. Times for each case were recorded in minutes at different periods to find total surgical time (incision to closure), total time in the OR (time into room to time out of room), and preparation time (time into room to incision time). The total number of trays was calculated based on the manufacturer's trays prepared for and opened for the case determined by the surgeon's request. For example, if the case was posted for TSA vs. RSA or standard vs. augmented

Table I
Comparison of baseline characteristics, preoperative measurements, and function between groups.

	Group 1 (n = 65)	Group 2 (n = 29)	*P* value
Average age	71 ± 8.8	69.8 ± 9.5	.577
Male (%)	35 (54)	16 (55)	.966
BMI (kg/m^2)	29.7 ± 6.5	30.3 ± 6.7	.727
Average ASA score	2.6 ± 0.6	2.4 ± 0.6	.167
Average number of comorbidities	2.7 ± 1.5	2.8 ± 1.4	.847
Right arm (%)	25 (38)	13 (45)	.695
Glenoid version (°)	−11.1 ± 17.6	−16.4. ± 12.5	.269
Glenoid inclination (°)	7.1 ± 11.5	5.9 ± 8.3	.701
Flexion (°)	154.84 ± 21.4	156.1 ± 27.1	.833
Abduction (°)	149.1 ± 27.0	160.4 ± 20.5	.058
External rotation (°)	44.3 ± 20.1	44.8 ± 23.1	.918

BMI, body mass index; *ASA*, American Society of Anesthesiologists.

components, all the trays would have been opened rather simply TSA or augmented RSA, which did occur when the preoperative plan was used specifically as a guide in surgery. Instrumentation trays were not included in the number of trays used for sterilization as this is standardized for all primary SA cases and exists on the shelf. The cost of sterilization per case was calculated by multiplying the standard cost of sterilization per tray at our institution of $100 by the number of trays used. Confounding variables such as glenoid inclination, version, and Walch classification were included to account for the degree of difficulty of surgery. Patient outcomes, function, and pain frequency were recorded with a minimum 3 months follow-up. The range of motion at the most recent patient follow-up available was recorded, including external rotation, internal rotation, abduction, and flexion.

Statistical analysis

Statistical analyses included the T-test, ANOVA, and Pearson's correlation with a $P < .05$ defined for significance. Potential confounding variables were explored in subanalyses using glenoid type and surgical time for both groups. Statistical analysis was conducted using SPSS 24.0 software (IBM, Armonk, NY, USA).

Results

Ninety-four patients met inclusion criteria and were divided into their two respective groups based on the use of preoperative planning software intraoperatively. Group 1 consisted of 65 patients, and the control group (group 2) included 29 patients. The two groups were comparable at baseline as there was no significant difference in age, gender, BMI, ASA class, number of comorbidities, and affected arm between groups (Table I). The groups were also comparable in glenoid version and inclination, preoperative range of motion (Table I), and preoperative patient-reported outcomes (Table II).

Group 1 had an average surgical time of 118.9 ± 26.2 minutes, and group 2 had an average of 111.9 ± 27.2 minutes with no significant difference between groups ($P = .253$). Group 1 had an average OR time of 183.1 ± 30.3 minutes, and group 2 had an average OR time of 173.2 ± 30.3 minutes with no significant difference between groups ($P = .160$). Time for preparation was comparable between the groups; group 1 had an average time of 53.5 ± 18.9 minutes compared to 53.1 ± 20.3 minutes for group 2 ($P = .924$) (Table III).

When accounting for potential factors affecting time and efficiency in the OR, overall, there was a difference in distribution between glenoid type in the two cohorts with A2 glenoid type being the largest group (39.13%). Overall, there was no association between glenoid types and surgical time ($P = .770$). No significant difference in surgical time was noted between groups for each glenoid type (Table IV). The average glenoid version measured for group 1 was −11.6° ± 17.6° as compared to −16.4° ± 12.5° for group 2 ($P = .269$). Similarly, the average glenoid inclination for group 1 was 7.1° ± 11.5° and 5.9° ± 8.3° for group 2 ($P = .701$) (Table II).

For group 1, there was an average of 5 trays used per case compared with 8 trays used in group 2 ($P < .001$). The cost of sterilization for group 1 was $487.30, which was significantly less than the cost for group 2 averaging $842.68 ($P < .001$) (Table IV). Additionally, no correlation between the number of trays and preparation time for group 1 (r = −0.05) or group 2 (r = −0.28) was found, and no correlation was found for the number of trays and surgical time for group 1 (r = −0.06) or group 2 (r = −0.03).

Outcomes were recorded at 6 weeks and 3 months postoperatively. There were no significant differences for postoperative pain scores (numeric rating scale [NRS]) at rest, with normal activity, or with strenuous activities at both periods of follow-up. No significant differences between groups were found for ASES Shoulder scores, PENN scores, and SSV scores at either follow-up visit (Table V).

Table II
Preoperative patient outcomes compared between groups.

	Group 1	Group 2	*P* value
NRS now	5.9 ± 3.6	5.0 ± 3.5	.404
NRS at rest	4.3 ± 3.5	2.8 ± 3.0	.154
NRS normal activity	7.7 ± 3.4	6.7 ± 2.9	.33
NRS strenuous activity	8.8 ± 2.8	8.2 ± 2.9	.457
ASES pain	20.4 ± 17.9	25 ± 18.0	.404
Total Penn	20.7 ± 8.3	17.7 ± 7.4	.232
Penn pain	9.3 ± 8.2	13.5 ± 7.4	.086
SSV	19.8 ± 22.4	31.1 ± 24.5	.142
Penn satisfaction	1.6 ± 2.8	2.0 ± 3.2	.704
Penn function	10.5 ± 9.4	15.1 ± 10.6	.162
ASES function	11.5 ± 9.4	14.5 ± 9.6	.319

NRS, numerical rating scale; *ASES*, American Shoulder and Elbow Surgeons; *SSV*, Subjective Shoulder Score.

Table III
Intraoperative data comparison between groups.

	Group 1	Group 2	*P* value
Surgical time (min)	118.2 ± 26.2	111.9 ± 27.2	.252
Operating room time (min)	183.2 ± 32.1	173.2 ± 30.3	.160
Preparation time	53.5 ± 18.9	53.1 ± 20.3	.924
Number of trays	4.9 ± 0.3	8.4 ± 2.9	<.001*
Cost of sterilization ($)	487.30 ± 34	842.86 ± 290	<.001*

*Denotes significance ($P < .05$).

Table IV
Comparison of surgical time by glenoid type for each group.

Group	Glenoid type	Surgical time (min)	*P* value
1	A1	126.00 ± 22.0	.883
	A2	115.57 ± 28.5	
	B1	116.44 ± 29.2	
	B2	118.33 ± 25.2	
	B3	118.2 ± 25.7	
2	A1	113.60 ± 11.5	.068
	A2	132.00 ± 29.6	
	B2	88.75 ± 8.7	

Discussion

This study investigated if 3D preoperative planning software use would decrease the cost and increase OR efficiency in patients undergoing SA. With the growing demand for shoulder arthroplasty, understanding the various aspects of surgery that can influence OR time and surgical costs are imperative. Further, analysis of new tools presumed to improve outcomes and surgical efficiency should be regularly assessed and validated. In our study, after controlling for case complexity, we did not find any statistically significant difference in time spent in the operating room when comparing preoperative plan use. However, there was a significant cost saving with a decrease in the number of trays used directly translating into a significant reduction in sterilization costs and the number of trays needed per case.

Although previous studies have analyzed 3D preoperative planning software's ability to accurately predict intraoperative implant selection, our results demonstrated that this did not necessarily translate into reduced surgical time or OR efficiency. Given the complexity of tracking and understanding operating room costs, we were unable to see a direct impact of preoperative planning on overall OR efficiency. Advocates say the use of preoperative planning adds only 10-15 minutes in preparation time for a surgeon and clearly impacts the surgeon's accuracy and implant selection, which may impact implant failures rates long term. Although if the time allocated to planning cases was recorded and added to the little impact in operative times or early outcomes, skeptics might say preoperative planning is unneeded., Other downstream quantifiable efficiency improvements have been identified in the literature. Cichos et al. identified decreased cleaning and room turnover time with tray optimization.[7]

Focus has risen on surgical costs and efficiency through enhancing surgical tray usage. In our study, the use of preoperative planning did significantly decrease the number of trays, directly translating into a significant reduction in sterilization cost and lesser number of trays needed per case. Studies have confirmed optimizing surgical tray use during a procedure can reduce cost, preparation time, and increase operating room efficiency.[6,9,26] The accuracy of 3D preoperative planning has correctly predicted the size of SA components and glenoid measurements used intraoperatively.[16,17,19,20,21,23,29] Thus, it is possible to minimize the number of instruments and trays used in a shoulder arthroplasty procedure based on the use of preoperative planning.

Previous literature has shown the majority of short-term costs with SA are operative costs and can be attributed to implant-specific costs, which is a modifiable factor.[5] In this study, we were unable to compare cost of implants, as a single system was used with set institutional pricing for the type of case. In addition, RSA has been shown to be more expensive than TSA mainly due to costlier implants.[24] Since our cohort overall had significantly had more patients undergoing RSA than TSA, this variable could not be compared for surgical costs and operative time. Although our study could not incorporate implant costs, it does examine continuous process improvement strategies with surgical trays. Cost-saving was appreciated with a 42% decrease in sterilization cost associated with preoperative planning use. Previous studies have highlighted the impact of this method on reducing operating room costs, most notably in hip and knee arthroplasty, where tray optimization resulted in an annual savings of $159,600 in sterile processing costs.[4] To our knowledge, our study is the first to analyze sterilization cost savings using preoperative planning for shoulder arthroplasty.

Limitations of this study included a small sample size and quality of the OR data that limited our ability to analyze confounding factors. In addition, the cohort sizes were not equally based on the surgeon's practice evolution and available data. There was, however, no selection bias, given that all patients underwent preoperative planning regardless of pathology or patient characteristics. With an increased sample size, our study may have had the power required for the small differences in types of surgery, patient factors, variations in minutes, and costs that may have been statistically significant. Numerous confounding variables across institutions such as the presence of consistent teams, specialized services, fellows, residents, and medical students can drastically change both surgical cost and surgical time.[15,27] Time allocated to dynamic education or specialized teams in the OR is not recorded in hospital systems but should be integrated to accurately evaluate and understand operating time and costs. Moreover, hospital tracking of additionally needed instruments and problems with sterilization or case delays was not available to be studied.[5,14,24,30] Advancements in OR tracking, from both a provider and hospital

Table V
Comparison of postoperative patient-reported outcomes.

	6 weeks postoperative			3 month postoperative		
	Group 1	Group 2	*P* value	Group 1	Group 2	*P* value
NRS now	2.0 ± 3.1	2.1 ± 2.4	.96	0.5 ± 1.4	0.5 ± 1.4	.933
NRS at rest	2.5 ± 3.5	1.8 ± 2.5	.572	0.5 ± 1.2	0.3 ± 0.9	.682
NRS normal activity	3.9 ± 4.1	2.7 ± 3.5	.399	1.6 ± 1.7	1.1 ± 1.9	.023*
NRS strenuous activity	5.3 ± 4.1	4.2 ± 3.9	.481	3.2 ± 3.2	2.8 ± 2.7	.685
ASES pain	40.0 ± 15.7	39. ± 11.8	.96	47.7 ± 6.0	46.3 ± 8.7	.596
Total Penn	11.1 ± 10.7	8.6 ± 9.4	.52	4.8 ± 4.6	4.3 ± 5.0	.798
Penn pain	18.0 ± 11.0	21.4 ± 9.4	.52	24.8 ± 5.3	25.7 ± 5.0	.630
SSV	60.3 ± 30.3	69.1 ± 22.5	.394	81.8 ± 18.8	81.0 ± 21.7	.909
Penn satisfaction	5.3 ± 4.2	7.6 ± 2.1	.157	7.3 ± 2.4	9.0 ± 5.4	.243
Penn function	21.3 ± 12.4	23.9 ± 15.3	.613	33.0 ± 13.7	39.7 ± 18.6	.245
ASES function	19.7 ± 9.8	23.0 ± 11.9	.431	11.5 ± 9.4	14.5 ± 9.6	.319

NRS, numerical rating scale; *ASES*, American Shoulder and Elbow Surgeons; *SSV*, Subjective Shoulder Score.
*Denotes significance ($P < .05$).

perspective, need to take place if we want to accurately understand surgical costs and better analyze new surgical tools aimed at increasing surgical efficiency.

Conclusion

Our study demonstrates that 3D preoperative planning resulted in a reduction in tray utilization and sterilization cost. We also observed that at both 6 weeks and 3 months postoperatively, there was no difference in pain, function, and satisfaction between the two groups. At our institution, in this patient population, surgical complexity was not a factor in influencing operative time, costs, or postoperative patient-reported outcomes. There was no correlation found between preoperative planning and time in the operating room. Increased attention to an efficient recording of potential variables that can affect OR time or efficiency may help future studies.

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