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Patient-specific planning in shoulder arthroplasty

INFLUENCING THE LEARNING CURVE FOR ASSESSMENT OF THE GLENOID AND SURGICAL PLANNING

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Aims
Patient-specific instrumentation has been shown to increase a surgeon's precision and accuracy in placing the glenoid component in shoulder arthroplasty. There is, however, little available information about the use of patient-specific planning (PSP) tools for this operation. It is not known how these tools alter the decision-making patterns of shoulder surgeons. The aim of this study was to investigate whether PSP, when compared with the use of plain radiographs or select static CT images, influences the understanding of glenoid pathology and surgical planning.

Methods
A case-based survey presented surgeons with a patient's history, physical examination, and, sequentially, radiographs, select static CT images, and PSP with a 3D imaging program. For each imaging modality, the surgeons were asked to identify the Walch classification of the glenoid and to propose the surgical treatment. The participating surgeons were grouped according to the annual volume of shoulder arthroplasties that they undertook, and responses were compared with the recommendations of two experts.

Results
A total of 59 surgeons completed the survey. For all surgeons, the use of the PSP significantly increased agreement with the experts in glenoid classification ($x^2 = 8.54$; $p = 0.014$) and surgical planning ($x^2 = 37.91$; $p < 0.001$). The additional information provided by the PSP also showed a significantly higher impact on surgical decision-making for surgeons who undertake fewer than ten shoulder arthroplasties annually ($p = 0.017$).

Conclusions
The information provided by PSP has the greatest impact on the surgical decision-making of low volume surgeons (those who perform fewer than ten shoulder arthroplasties annually), and PSP brings all surgeons in to closer agreement with the recommendations of experts for glenoid classification and surgical planning.

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Introduction

According to the Agency of Healthcare Research and Quality, 53,000 shoulder arthroplasties were performed in the USA in 2011.[1] By 2020, this figure is projected to rise above 160,000. Currently, the annual rate of growth for total shoulder arthroplasty (TSA) is 13%.[2,3] Comparatively, these rates for total hip (THA) and knee arthroplasty (TKA) have been 4.5% and 7%, respectively.[4] Cram et al[4] showed that the rate of THA and TKA is reaching a plateau; however, the rate of shoulder arthroplasty is expected to continue to increase.[2]

It has been shown that achieving reliable outcomes in shoulder arthroplasty involves a steep learning curve.[5,6] Riedel et al[6] found that the learning curve for the technical aspects of reverse shoulder arthroplasty (RSA) was 18 cases. Kempton et al,[5] however, performed a complication-based study for RSA and found the learning curve to be 40 cases. The local complication rate was higher for the first 40 cases (23.1%) compared with that of the following 160 cases (6.5%). As expected, there is a direct correlation between surgical volume and outcomes, with higher-volume surgeons having lower

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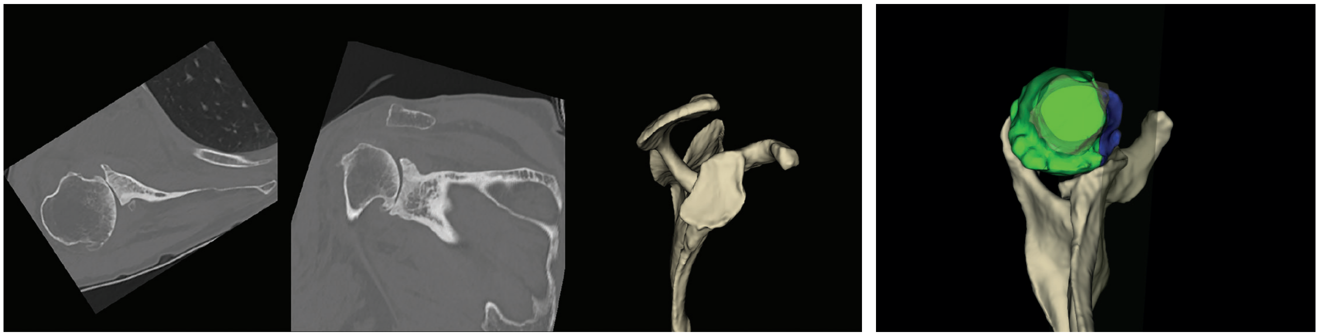

a b

Fig. 1

The patient is an 83-year-old, right hand dominant, female,who has chronic right shoulder pain. Shecan actively forward elevate 90°, externally rotate to neutral and internally rotate to her buttock. She has good rotator cuff strength. a) select static CT images and 3D reconstruction, and b) 3D rendering of the glenoid anatomy showing humeral head subluxation. Retroversion: 33˚; Superior inclination: 15˚; Posterior subluxation: 89%.

complication rates.[7,8] Weinheimer et al[9] undertook a systematic review of shoulder surgery and defined low-volume shoulder arthroplasty surgeons as those performing fewer than five arthroplasties per year. These surgeons had increased complications, length of stay, operating time, and cost.

In the USA, 78% of surgeons who undertake shoulder arthroplasty perform only one or two arthroplasties annually, and only 3% of these surgeons perform more than ten arthroplasties annually.[10] As the popularity of TSA and RSA continues to increase, more low-volume surgeons are expected to be performing these procedures.

Matsen et al[11] reported that failures of the glenoid component are often due to failures in seating or fixing it, and the management of eccentric loading. Understanding the anatomy of the glenoid and these modes of failure can minimize complications after shoulder arthroplasty. A set of tools which help to improve a surgeon's understanding of shoulder pathology might affect the learning curve, help to avoid surgical errors, and improve outcomes after shoulder arthroplasty.

The aim of this study was to assess the influence of patient-specific planning (PSP) on glenoid classification and surgical planning for shoulder arthroplasty. We hypothesized that PSP would significantly improve a surgeon's understanding of the glenoid morphology and surgical plan.

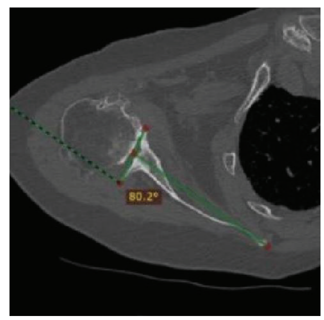

Fig. 2

Axial CT with Friedman Method[12] of a 75-year-old, right-hand dominant female with chronic right shoulder pain. She could actively forward elevate to 80°, externally rotate to neutral, and internally rotate to her buttock. The Friedman method was used to calculate glenoid retroversion. Using a 2D CT, the transverse axis of the scapula is determined by a line drawn from the mid-point of the glenoid fossa to the medial edge of the scapula. The line drawn perpendicular to the transverse axis is defined as the line of neutral version. In order to calculate glenoid version, a line is drawn between its anterior and posterior margins. The angle between the line of neutral version and the line connecting the anterior and posterior margins determines the version, showing retroversion of 9.8°.

Methods

A case-based survey was created to assess surgical planning for shoulder arthroplasty. For each case, a brief history, physical examination, and one of three imaging methods were provided in sequence. The imaging methods were plain radiographs with the standard anteroposterior and axillary views, select static CT images, and PSP with a 3D imaging program (Figure 1). On the CT scans, retroversion of the glenoid was presented using the Friedman Method (Figure 2).[12] Specific preselected CT cuts and corresponding measurements were provided for consistency. PSP was performed using an imaging program which provides a 3D reconstruction of the glenoid and corrected axial 2D images that are in the plane of the scapula. These images allow for more accurate assessment of glenoid version and humeral subluxation.[13] The software provided the exact version of the glenoid and the percentage subluxation of the humeral head relative to the centre of the glenoid and the axis of the body of the scapula.

For every case, the three imaging methods were presented in the same sequence, first the radiographs, then the CT, and finally the PSP. With the presentation of each modality, the following questions were asked: "What is the Walch classification for this glenoid?"[14-16] (Table I) and "What type of arthroplasty would you perform?" (Table II). The survey was created so that the respondent would not be able to modify their previous answers.

An online questionnaire service was made available to shoulder surgeons of varying levels of experience. The following demographic information was asked of them: age, sex, years of practice since completion of residency, number of shoulder arthroplasties performed annually, and fellowship(s) completed. The surgeons were grouped according to their surgical volume. Group 1 performed more than 40 arthroplasties

Table I. Survey options for identification of the Walch glenoid classification.

"What is the Walch classification for this glenoid?"
1: A1
2: A2
3: B1
4: B2
5: B3
6: C
7: D
8: Unable to Classify
9: N/A

Table II. Survey options for identification of the optimal surgical treatment.

"What type of arthroplasty would you perform?"
1: Total shoulder, maintain current glenoid version
2: Total shoulder, asymmetric reaming to re-establish native glenoid version
3: Total shoulder, reconstruct glenoid with bone graft
4: Total shoulder, augmented glenoid
5: Reverse shoulder, maintain current glenoid version
6: Reverse shoulder, asymmetric reaming to establish neutral glenoid version
7: Reverse shoulder, reconstruct glenoid with bone graft
8: Reverse shoulder, augmented base plate
9: Hemiarthroplasty

annually,[5] group 2 performed between 11 and 40 arthroplasties, and the low-volume group 3 surgeons performed fewer than ten arthroplasties annually.[6] The expert recommendations were established with the consensus of two shoulder surgeons (JPW, GW) who are directors of a shoulder and elbow fellowship, have more than 30 years of experience with shoulder arthroplasty, and perform more than 100 arthroplasties annually. These senior surgeons are from different institutions and have differing training backgrounds. No external funding or support of any kind was used for this study.

Statistical analysis. An a priori sample size calculation was performed to determine the number of respondents required to achieve 80% power. Based on an expected correlation coefficient of > 0.50 (H0 = 0.40), data from 42 respondents would need to be collected. Statistical analyses were performed in SPSS (V22, IBM, Armonk, New York, USA). Significance for all tests was set at $p < 0.05$. Standard descriptive statistics were used to describe aggregate data. Two-tailed Z-tests were used to compare proportions of agreement. chi-squared tests were used to assess the association between the type of imaging sequence and the proportion of agreement. Binomial logistic regression models were built to assess the association of group of surgeon experience with the degree of agreement with the 'expert recommendation' for glenoid classification or surgical plan.

Results

A total of 59 surgeons completed the survey. Their mean age was 40.6 years (31 to 64); there were 54 men and five women. The mean duration of clinical practice was 8.7 years (standard deviation (SD) 8.5; 1 to 39). A total of 27 were in group 1, 17 were in group 2, and 15 were in group 3 (Table III). The two

Table III. Demographic details of the participants.

Characteristic	n
Respondents	59
Sex, male:female	55:4
Mean time in practice, yrs	8.7 (1 to 39)
Group 1 (> 40)	27
Group 2 (11 to 40)	17
Group 3 (1 to 10)	15
Fellowship	
Shoulder and elbow	36
Sports	8
None	1
In training	14

senior surgeons showed 91.7% agreement in establishing the recommendation, only differing in one glenoid classification (B2 versus B3) which was settled by discussion; all the surgical plans were agreed.

Agreement: glenoid classification. The group 1 surgeons had the highest rate of agreement with the experts for glenoid classification. Group 3 surgeons had the lowest agreement. A total of 22 surgeons (37%) agreed with the experts in the classification of the glenoid based on radiographs alone, 22 (37%) when given the CT, and 27 (46%) when given the PSP. For all surgeons, PSP significantly increased agreement in glenoid classification (x^2: 8.54, $p = 0.014$, chi-squared test) (Table IV). When assessing the impact of the imaging modality and surgical volume on glenoid classification, there was no statistically significant relationship.

Agreement: surgical plan. The group 1 surgeons had the highest rate of agreement with the experts for the surgical plan, while the group 3 surgeons had the lowest rate (Table IV). When given the radiographs alone, 20 surgeons (34%) agreed with the experts, 18 (30%) using the CT, and 30 (51%) when using the PSP. For all surgeons, PSP significantly increased agreement with the experts' recommended surgical plan (x^2 = 37.91; $p < 0.001$, chi-squared test). A subanalysis did not show any statistically significant trends in surgical planning within the groups (Table V).

When assessing the change in surgical plan after being provided with various imaging methods, the plan following the radiographs versus the plan following the addition of the CT, there was no significant change in the decision for all levels of experience (Table V). When comparing the surgical plan made with the information provided by the radiographs versus the decision when using the PSP, there was a significant change in the plan for group 3 ($p = 0.017$, logistic regression analysis), and a trend towards significance for group 1 ($p = 0.050$, logistic regression analysis) (Table VI).

Discussion

Gonzalez et al[17] found that most failures in shoulder arthroplasty are avoidable, being usually due to a diagnostic error, technical error, or a combination of both. We found that the information provided by the PSP brought all surgeons into closer agreement with the experts for both glenoid classification and the surgical plan, but that the PSP had the greatest benefit for low-volume surgeons. By having the information from all methods,

Table IV. The rates of agreement with the experts for both glenoid classification and surgical plan, across the three imaging methods.

Question	Group	Radiograph, %	CT, %	PSP, %	x^2	p-value*
Glenoid	1	36.4	35.2	48.8	N/A	N/A
Glenoid	2	35.3	44.1	47.1	N/A	N/A
Glenoid	3	40.0	32.2	41.1	N/A	N/A
Glenoid	1, 2, 3	37.0	37.0	46.3	8.537	0.014
Surgical plan	1	40.7	33.3	56.8	N/A	N/A
Surgical plan	2	35.3	28.4	52.0	N/A	N/A
Surgical plan	3	21.1	26.7	41.1	N/A	N/A
Surgical plan	1, 2, 3	34.2	30.2	51.4	37.91	<0.001

Chi-squared test.
N/A, not applicable; PSP, patient-specific planning.

Table V. Regression model to assess the association of covariates such as imaging methods, years in practice, and surgical volume (groups) with the degree of agreement with the experts' recommendation in determining the surgical plan.

Group	Radiograph vs CT*					CT vs PSP†					Radiograph vs PSP‡				
	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value
Experience	0.005	1.005	0.975	1.036	0.739	0.013	0.987	0.957	1.018	0.394	0.017	1.018	0.987	1.049	0.264
Group 1	N/A	N/A	N/A	N/A	0.801	N/A	N/A	N/A	N/A	0.531	N/A	N/A	N/A	N/A	0.050
Group 2	0.124	1.132	0.675	1.899	0.639	0.029	0.971	0.579	1.629	0.912	0.169	1.184	0.705	1.989	0.523
Group 3	0.208	1.231	0.648	2.339	0.525	0.313	1.368	0.716	2.613	0.343	0.795	2.213	1.155	4.242	0.017

*Plain radiographs versus CT, reflecting the change in decision/answer when presented with only the plain radiographs versus when provided with the additional information of the CT.
†CT versus patient-specific planning, reflecting the change in decision/answer when presented with the plain radiographs and CT versus when also using patient-specific planning.
‡Plain radiographs versus patient-specific planning, reflecting the change in decision/answer when presented with just the plain radiographs versus when also provided with the CT and patient-specific planning. B, beta; CI, confidence interval; N/A, not applicable; PSP, patient-specific planning.

Table VI. Regression model to assess the association of covariates such as imaging methods, years in practice, and surgical volume (groups) with the degree of agreement with the experts' recommendation in the determination of glenoid classification.

Group	Radiograph vs CT*					CT vs PSP†					Radiograph vs PSP‡				
	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value	B	Exp (B)	Lower 95% CI	Upper 95% CI	p-value
Experience	0.002	0.998	0.968	1.029	0.913	0.002	0.998	0.968	1.029	0.913	0.021	1.021	0.988	1.055	0.208
Group 1	N/A	N/A	N/A	N/A	0.521	N/A	N/A	N/A	N/A	0.521	N/A	N/A	N/A	N/A	0.371
Group 2	0.299	1.349	0.800	2.272	0.261	0.299	1.349	0.800	2.272	0.261	-0.250	0.778	0.460	1.319	0.352
Group 3	0.107	1.113	0.586	2.117	0.743	0.107	1.113	0.586	2.117	0.743	0.173	1.189	0.613	2.307	0.609

*Radiograph versus CT, reflecting the change in decision/answer when presented with just the radiographs versus when provided with the additional information of the CT.
†CT versus patient-specific planning, reflecting the change in decision/answer when presented with the radiographs and CT versus when also provided with the patient-specific planning.
‡Radiographs versus patient-specific planning, reflecting the change in decision/answer when presented with just the radiographs versus when also provided with the CT and patient-specific planning.
B, beta; CI, confidence interval; N/A, not applicable; PSP, patient-specific planning

radiographs, CT, and PSP, the low-volume surgeons had a better understanding of the shoulder. As most surgeons who perform shoulder arthroplasty are considered low-volume, as they undertake fewer than ten arthroplasties annually, the added information provided by PSP may improve understanding of the shoulder and affect the learning curve for the less experienced surgeons, to bring them into closer agreement with more experienced surgeons.

There have been conflicting reports of the efficacy of PSP and instrumentation in THA and TKA.[18,19] Short- to mid-term follow-up studies have shown that robotic-assisted THA and TKA decreases variability with trends toward decreased revision rates. Further studies are required to provide the cost-effectiveness of these tools.[20] Consistent, long-term improvements in patient-reported outcomes have not been reported using patient-specific surgical instruments, compared with outcomes when using traditional instruments, and these technologies have not been widely adopted.

PSP may be beneficial in shoulder arthroplasty because many of the anatomical landmarks and reference points used to guide the implantation of the glenoid component are obscured by soft tissues or are not within the surgical field. Moreover, the scapula moves on the chest wall, making it difficult to place the component in the optimal position. Since the glenohumeral joint is a 'ball-on-a-socket' rather than a 'ball-in-a-socket', the orientation of the glenoid and position of the humeral head may substantially influence durability due to non-concentric loading.[11,21] The introduction of a stable glenoid component in patients with glenoid deformity may be difficult.

Malpositioning of the glenoid component is the most common cause of failure after shoulder arthroplasty, accounting for 24% of all complications.[11,17] This malpositioning generates abnormal forces across the glenoid, known as the 'rocking horse phenomenon'.[22-25] Placing the glenoid in 15° of retroversion increases micromotion at the bone-cement interface,[21,22] and placing it in > 15° of retroversion will lead to eccentric loading, increased wear, loosening, and osteolysis.[21,26,27] Walch et al,[28] in a series of 92 TSAs, showed that B2 and C glenoids placed in retroversion can do well for a short time. However, at a mean follow-up of 6.4 years, there was a revision rate of 16.3% due to glenoid loosening. Malpositioning is usually related to a failure to recognize the severity of glenoid deformity. The Friedman method is the most common and reproducible method of measuring glenoid retroversion on 2D CT.[12,29] It has excellent interobserver and intraobserver reliability.[12,30,31] However, Budge et al[32] showed that axial 2D CT measurements of retroversion can be up to 15° different than those of 3D measurements. Much of this is due to the fact that glenoid retroversion on 2D CT depends on the position of the scapula when the CT is acquired.[31] Using 3D CT, Paul et al[33] found that 1.8% of 1437 patients who presented to their tertiary centre with shoulder pathology had a Walch C glenoid with a mean retroversion of 38°. The position of the scapula cannot be controlled when taking a CT. Therefore, there is no consistent reference for the measurement of retroversion. When retroversion is underestimated, the operation may be destined to fail. Thus, a critical step in the operation is the placement of the guide wire for reaming the glenoid. Many arthroplasty systems use a guidewire as a reference for glenoid version. However, there are no reliable anatomical landmarks to inform the surgeon about glenoid version during surgery. Thus the placement of the glenoid component is highly variable. It has been shown that its position may deviate by between 8° and 10° from the intended position.[34,35] Difficult exposure and lack of landmarks commonly lead to glenoid malpositioning.[11,17]

PSP can help to reduce the variations in guidewire placement. In a study using cadavers, Walch et al[36] showed excellent correlation between the position of the guidewire on preoperative planning and the position at the time of implantation, using patient-specific instrumentation. Hendel et al[34] performed a randomized control trial using standard techniques for the placement of wires compared with placement using patient-specific instrumentation. They found that the use of patient-specific instrumentation significantly reduced the mean deviation of the guidewire from its intended position and ultimately the position of the glenoid component. The largest benefit was seen in patients with preoperative retroversion > 16°.

Appropriate placement of the guidewire is also pivotal in RSA, which may be used to treat rotator cuff-deficient shoulders. However, it is also used for patients with severe glenoid deformity, fractures, and as a revision procedure. In these complex scenarios, surgical exposure can be extremely difficult and the glenoid vault can be compromised. Heylen et al[37] showed that with extreme deformity, although deviation from the intended surgical plan is common, the use of patient-specific instrumentation convincingly reduced the variability of the placement of the baseplate. The use of patient-specific instrumentation allows the accurate reproduction of a 3D preoperative plan.[38]

This study has limitations. It was a survey-based study with inherent limitations. We surveyed surgeons with an interest in shoulder surgery who are likely to have an enhanced understanding of the anatomy and pathology of the shoulder. The 'expert' recommendation involved the opinion of two experienced surgeons. Although they demonstrated a high rate of agreement, the 'expert' nature of their recommendations could be questioned. This is reflected in our findings; even with the PSP only 27 surgeons (46%) agreed with the glenoid classification. This may reflect some misunderstanding of Walch's classification of glenoid anatomy. Furthermore, even with PSP, only 30 surgeons (51%) agreed with the surgical plan. In most orthopaedic procedures, there is debate about the 'best' treatment. The 'best' form of THA remains controversial. In anterior cruciate ligament reconstruction, the 'best' choice of graft remains controversial. Similarly, in shoulder arthroplasty, there is debate about the management of severe glenoid dysplasia. Although we used the recommendations of two senior shoulder 'experts', we acknowledge that there may be several effective surgical solutions for each patient.

We found that information provided by PSP had the greatest impact on the surgical plan for surgeons who perform fewer than ten shoulder arthroplasties annually, and that its use brought all surgeons in to closer agreement with the 'experts' for glenoid classification and surgical planning.

Take Home Message

- Patient-specific planning potentially improves decision-making of less experienced surgeons, bringing them to the level of more experienced surgeons.
- This may reduce errors in planning and increase successful outcomes in shoulder arthroplasty.

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