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Three-dimensional measures of posterior bone loss and retroversion in Walch B2 glenoids predict the need for an augmented anatomic glenoid component

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Hypothesis: The purpose of this study is to evaluate whether the amount of measured posterior bone loss on 2- and 3-dimensional (2D and 3D) imaging of Walch B2 glenoids can reliably predict the plan for an augmented anatomic glenoid component.

Methods: Patients with Walch B2 glenoids and preoperative computed tomography (CT) scans were retrospectively identified. 2D axial CT scans were reviewed and posterior bone loss was measured by 3 independent reviewers. Images were then formatted into BluePrint (Wright Medical) preoperative planning software. The same 3 reviewers again measured posterior bone loss on 3D imaging. Additionally, all cases were planned with BluePrint software. An augment was used when the following criteria were unable to be satisfied with standard implants: $<10°$ retroversion, $<10°$ superior inclination, $\geq 90\%$ backside contact, <2 mm medial reaming, and ≤ 1 peg perforation.

Results: Forty-two patients were included in the final analysis with a mean age of 63.1 ± 6.3 years. As measured by BluePrint, the mean retroversion was 23° ± 7° (range = 9°-40°), the mean superior inclination was 5° ± 6° (range = –9° to 22°), and the mean posterior subluxation was 80% ± 17% (range = 41%-95%). The mean 2D bone loss measurements (3.5 ± 1.6 mm) were significantly lower than the mean 3D bone loss (4.0 ± 1.8 mm) measurements ($P = .03$). There was substantial agreement between reviewers on both 2D and 3D measurements with an interclass correlation of 0.815 (95% confidence interval [CI] 0.714-0.889, $P < .001$) and an interclass correlation of 0.802 (95% CI 0.683-0.884, $P < .001$), respectively. Augments were used in 73.8%, 63.4%, and 63.4% of cases by reviewers 1, 2, and 3, respectively, with moderate agreement with a Fleiss kappa of 0.592 (95% CI 0.416-0.769, $P < .001$). Augment size was moderately, positively correlated with the amount of bone loss on 3D imaging but not with 2D imaging. After multivariate logistic regression, both 3D bone loss and retroversion were found to be predictive for a plan to use an augment.

Conclusion: Planning for a posterior augment in Walch B2 glenoids is better predicted with 3D imaging than with 2D imaging, as 2D imaging may underestimate posterior bone loss. Additionally, use of a larger augment size is moderately correlated with posterior bone loss on 3D imaging but not 2D imaging. Standard 2D imaging may be limited in cases of posterior bone loss, and 3D imaging may be beneficial for preoperative planning in Walch B2 glenoids.

Level of evidence: Level IV; Case Series; Prognosis Study

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Keywords: Shoulder; shoulder arthroplasty; bone loss; glenoid deformity; B2 glenoid; anatomic total shoulder arthroplasty

Thomas Jefferson University Institutional Review Board approved this study (20E.255).

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Acquired glenoid deformity secondary to erosive posterior bone loss presents unique challenges during anatomic shoulder arthroplasty. Posterior bone loss is common and can be present in 40%-50% of patients undergoing primary shoulder arthroplasty.[2,6,29] Posterior glenoid bone loss can be problematic as it results in loss of subchondral bone, decreased glenoid vault distance, medialization of the joint line, and humeral head subluxation. Increased amounts of posterior glenoid erosion have been associated with poor outcomes during anatomic shoulder arthroplasty with traditional polyethylene glenoid components.[16,32] Walch et al[32] reported 21% glenoid loosening at 6 years in a cohort of patients with B2 glenoid morphology and an average posterior bone loss of 7 mm. Furthermore, patients with greater posterior bone loss had higher complications.[32] Augmented glenoid components have recently been advocated for patients with more advanced posterior bone loss, with encouraging early results.[8,13,30,38] Currently, there is no consensus for when patients with B2 glenoid morphology should be treated with an augmented component.

Accurate assessment of glenoid morphology is critical in order to determine how to best address the deformity surgically. Three-dimensional (3D) preoperative planning software has been advocated for patients with more advanced glenoid deformity. Accurate and reproducible automated measurements of glenoid morphology can be determined, which are more reliable for assessing the magnitude and location of glenoid bone loss in comparison to 2-dimensional (2D) images.[9,14,24,33] This software also allows for virtual component placement to be optimized and dynamically adjusted to account for the patient's version, inclination, and bone loss. Studies have demonstrated that 3D preoperative templating influences operative decision-making regarding component selection and the need for glenoid augmentation.[12,16,24]

Standard 2D images may be limited most notably because they are aligned to the plane of the body as opposed to the plane of the scapula. Intrinsic variation within the glenoid as well as scapular position can influence measurements of glenoid version.[3,4,18] Two-dimensional computed tomography (CT) underestimates glenoid retroversion in 20%-50% of patients and also underestimates humeral head subluxation.[5,14,17,26] However, 2D imaging may still provide a reliable assessment of posterior bone loss in patients with B2 glenoid morphology relative to the paleoglenoid, which can potentially be used to determine whether an augmented glenoid component may restore glenohumeral anatomy.

The purpose of this study is to evaluate whether the amount of measured posterior bone loss on 2D and 3D imaging of Walch B2 glenoids can reliably predict the plan for an augmented anatomic glenoid component. Our hypothesis is that the amount of posterior glenoid bone loss identified on 2D imaging will reliably predict both the plan for an augmented glenoid component and the size of the augmented component during 3D planning.

Methods

A consecutive cohort of patients with Walch B2 glenoid morphology and preoperative CT scans were retrospectively identified from an institutional database. Patients treated with both asymmetric reaming with standard glenoid components and augmented glenoid components were selected to ensure an appropriate mix of bone loss. 2D axial CT scans were reviewed and posterior bone loss was measured by 3 independent reviewers. All independent reviewers were shoulder and elbow fellowship–trained surgeons. To limit bias, reviewers were blinded from the ultimate treatment. Posterior glenoid bone loss was measured as the maximum amount of bone loss relative to a line parallel to the paleoglenoid (Fig. 1). Images were then formatted into BluePrint (Wright Medical, Memphis, TN, USA) preoperative planning software. The same 3 reviewers again measured posterior bone loss on 3D imaging with the same technique as described in Figure 1. Additionally, all cases were planned with BluePrint software. An augment was used in planning when the following criteria were unable to be satisfied with standard implants: $<10^\circ$ retroversion,[7,13,26] $<10^\circ$ superior inclination,[15,20,21,36,37,39] >90% backside contact,[31] <2 mm medial reaming,[28,34,35] and <1 peg perforation.[1]

Various statistical tests were performed. Normalcy of the data was determined using Shapiro-Wilk test. When the dependent variable was found to be not normally distributed, nonparametric tests were run. For reliability analysis, the following were used to determine the strength of agreement: 0 = poor, 0-0.20 = slight, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-1 = almost perfect. When comparing measurements between raters, inter-rater reliability was completed for continuous variables and Fleiss kappa was determined for qualitative data. Intrarater reliability was performed to assess agreement between each individual rater and the respective 2D and 3D measurements. Two analyses were performed to evaluate if augment use could be predicted based on measurements. A receiver operating characteristic curve was undertaken with area under the curve (AUC) analysis to determine if a specific cutoff value could be found. A second analysis with a multivariate logistical regression using a forward, stepwise likelihood model was created. Lastly, correlational analysis was done to assess if bone loss correlated with size of augment. All statistical analysis was carried out on Statistical Package for the Social Science (SPSS), version 26 (IBM Corp., Armonk, NY, USA). Statistical significance was defined at P values of <.05 for all output.

Results

Forty-two patients were included in this analysis with a mean age of 63.1 ± 6.3 years and included 30 (71.4%) males. As measured by BluePrint, the mean retroversion was 23° ± 7° (range = 9°-40°), the mean superior inclination was 5° ± 6° (range = –9° to 22°), and the mean

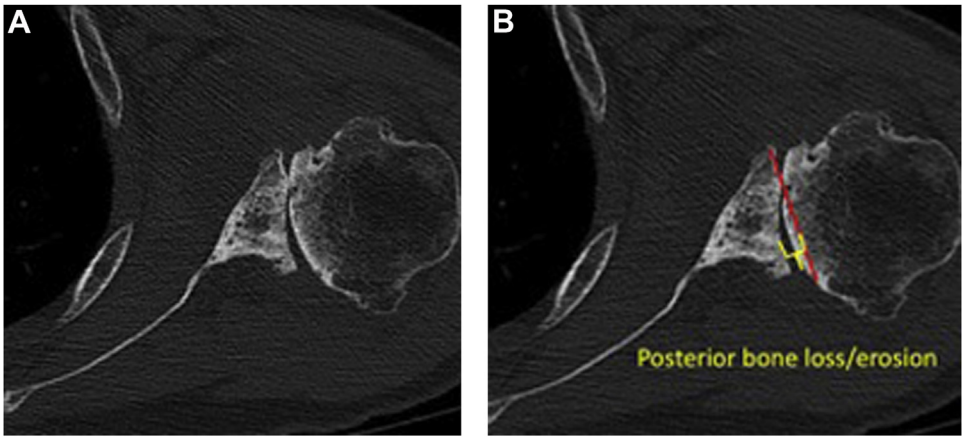

Figure 1 (**A**) Axial computed topography image of a Walch B2 glenoid with posterior bone loss. (**B**) Measurement of posterior bone loss. The *red line* represents an extension of the paleoglenoid. The *yellow line* is the measurement in mm from the line extending from the paleoglenoid to the neoglenoid.

posterior subluxation was 80% ± 17% (range = 41%-95%) (Table I).

The mean 2D bone loss measurements were 3.6 ± 1.5 mm, 3.7 ± 1.8 mm, and 3.3 ± 1.7 mm for reviewers 1, 2, and 3, respectively ($P = .717$). The mean 3D bone loss measurements were 4.2 ± 1.5 mm, 4.2 ± 1.9 mm, and 3.7 ± 1.8 mm for reviewers 1, 2, and 3, respectively ($P = .230$). Overall, 2D measurements were 3.5 ± 1.6 mm for all reviewers combined and 4.0 ± 1.8 mm for 3D measurements ($P = .030$). For 2D bone loss measurements, the raters found almost perfect agreement with an interclass correlation of 0.82 (95% confidence interval [CI] 0.71-0.89, $P < .001$). For 3D bone loss, the raters found substantial agreement with an interclass correlation of 0.802 (95% CI 0.68-0.88, $P < .001$).

Augments were used in 73.8%, 63.4%, and 63.4% of cases by reviewers 1, 2, and 3, respectively, with moderate agreement with a Fleiss kappa of 0.59 (95% CI 0.42-0.77, $P < .001$). Fleiss kappa for augment size showed moderate agreement at a value of 0.58 (95% CI 0.37-0.79, $P < .001$). Strongest agreement for both size analyses was found in the use of a 15° augment, and lowest agreement was for the 35° augment. Agreement between planned augment use and actual augment use is reported in Table II.

For reviewer 1, intrarater reliability showed substantial agreement at 0.519 (95% CI 0.35-0.83, $P < .001$). Reviewers 2 and 3 showed almost perfect agreement at 0.908 (95% CI 0.64-0.97, $P < .001$) and at 0.891 (95% CI 0.78-0.94, $P < .001$), respectively.

Prediction for the use of an augment based on 2D posterior bone loss

Receiver operating characteristic curves were calculated to predict the need for an augment based on measured 2D and 3D posterior bone loss (Tables III and IV). When the data were stratified based on whether the 2D measurement was ≤2.5 mm or greater, only reviewers 2 and 3 were predictive for the use of an augment (Table V). When the data were stratified based on whether the 2D measurement was ≤3 mm or greater, only reviewers 2 and 3 were predictive in the use of an augment (Table VI).

Prediction for the use of an augment based on retroversion

Overall, retroversion was the most predictive for the use of an augment, with all 3 reviewers finding moderate to strong predictive results. Reviewer 1 was strongly predictive of the use of an augment based on retroversion with an AUC of 0.92 (95% CI 0.84-1.00, $P < .001$). Reviewer 2 was moderately predictive of the use of an augment based on retroversion with an AUC of 0.88 (95% CI 0.78-0.98, $P < .001$). Reviewer 3 was moderately predictive of the use of an augment based on retroversion with an AUC of 0.89 (95% CI 0.79-0.99, $P < .001$). Using 22° of retroversion as a cutoff, reviewer 1 was 81% sensitive and 91% specific, and reviewers 2 and 3 were 85% sensitive and 80% specific, respectively, for the use of an augment.

Prediction for the use of an augment based on superior inclination

Superior inclination was not found to be predictive for the use of an augment. Reviewer 1 was not predictive of the use of an augment based on superior inclination with an AUC of 0.43 (95% CI 0.25-0.62, $P = .520$). Reviewer 2 was not predictive of the use of an augment based on superior inclination with an AUC of 0.45 (95% CI 0.27-0.63, $P = .588$). Reviewer 3 was not predictive of the use of an augment based on superior inclination with an AUC of 0.47 (95% CI 0.29-0.65, $P = .745$).

Table I Patient demographics (n = 42)

Sex, male, n (%)	30 (71.4)
Age, yr	63.1 ± 6.3
Retroversion, degrees	23 ± 7 (9 to 40)
Superior inclination, degrees	5 ± 6 (−9 to 22)
Posterior subluxation, %	78.0 ± 16.6 (8 to 95)

Unless otherwise noted, values are mean ± standard deviation (range).

Table II Agreement between planned augment use and actual augment use (n = 42)

	n (%)
Augment planned, augment used	26 (61.9)
Augment planned, augment not used	2 (4.8)
Augment not planned, augment used	8 (19.0)
Augment not planned, augment not used	6 (14.3)

Prediction for the use of an augment based on posterior subluxation

Reviewer 1 was moderately predictive of the use of an augment based on subluxation with an AUC of 0.85 (95% CI 0.74-0.97, $P = .001$). Reviewer 2 was moderately predictive of the use of an augment based on subluxation with an AUC of 0.82 (95% CI 0.69-0.95, $P = .001$). Reviewer 3 was fairly predictive of the use of an augment based on subluxation with an AUC of 0.78 (95% CI 0.68-0.93, $P = .003$).

Multivariate logistic regression analysis for augment use

After multivariate logistic regression, both 3D bone loss and retroversion were found to be predictive for the plan for an augment. For reviewer 1, retroversion and 3D bone loss measurements were found to be predictive for the use of an augment when the other variables were held constant. The odds ratio for retroversion was found to be 1.92 (95% CI 1.19-3.11) and for 3D bone loss to be 6.16 (95% CI 1.13-33.59). For reviewer 2, only retroversion measurements were found to be predictive for the use of an augment when the other variables were held constant. The odds ratio for retroversion was found to be 1.47 (95% CI 1.47-1.89). For reviewer 3, retroversion and 3D bone loss measurements were found to be predictive for the use of an augment when the other variables were held constant. The odds ratio for retroversion was found to be 1.80 (95% CI 1.10-2.93) and for 3D bone loss to be 4.54 (95% CI 1.38-14.95).

Bone loss and augment size

Augment size was moderately, positively correlated with amount of bone loss on 3D imaging but not with 2D imaging. For reviewer 1, the augment size selected was moderately, positively correlated to 2D bone loss measurement ($r = 0.553$, $P = .001$) and moderately, positively correlated to 3D bone loss measurements ($r = 0.600$, $P < .001$). For reviewer 2, augment size selected was moderately, positively correlated to 2D bone loss measurement ($r = 0.551$, $P = .004$) and moderately, positively correlated to 3D bone loss measurements ($r = 0.516$, $P = .007$), whereas for reviewer 3, 2D and 3D bone measurements were weakly and moderately, positively correlated to size of augment selected ($r = 0.392$, $P = .048$, vs. $r = 0.558$, $P = .003$), respectively.

After multivariate logistic regression, both 3D bone loss and retroversion were found to be predictive for the need to use an augment.

Discussion

We evaluated the ability of 2D CT to predict the need for an augmented anatomic glenoid component when compared to 3D imaging and preoperative templating. The main finding of this study was that 2D assessment of bone loss was not adequate for predicting the need for an augmented component. When using both 2.5 and 3.0 mm of posterior bone loss based on 2D imaging, augments were needed by all reviewers more than two-thirds of the time to achieve appropriate component position. Even in cases with minimal posterior bone loss (ie, <2.5 mm), augments were used in a significant amount of cases. This finding would favor the role of 3D planning even in the setting of minimal posterior loss in Walch B2 glenoids.

Another key finding of this study was that after multivariate logistic regression, both 3D bone loss and retroversion were found to be predictive for the need to use an augment. With greater than 22° of retroversion on 3D imaging, an augment was significantly likely to be needed to satisfy the component standards used in this cohort. This finding is consistent with previous studies that challenge the use of primary glenoid components in patients with significant retroversion without addressing the deformity. There are various strategies described to approach the B2 glenoid including asymmetric reaming, bone grafting, augmented glenoid components, or reverse shoulder arthroplasty. There is no consensus in the literature regarding these different approaches or the superiority of one specific technique.[11,19] Asymmetrically reaming down the high side is a widely used approach for small amounts of retroversion; however, over-reaming of the anterior glenoid has been associated with component failure as a result of the loss of subchondral support and medialization.[34] However, more recent data show that retroversion ≤15° can be treated with eccentric reaming. Sheth et al[27] compared 111 B2 glenoids with a mean retroversion of 15° treated with eccentric reaming to 178 A1 glenoids and found no difference in clinical or radiographic outcomes at

Table III Predicting the need for an augment based on 2D bone loss measurements

Reviewer	AUC	95% CI	*P* value	Bone loss, mm	Sensitivity, %	Specificity, %
1	0.661	0.478-0.844	.129	3.1	64.5	50.0
2	0.773	0.611-0.935	.004	2.9	76.9	66.7
3	0.846	0.729-0.964	<.001	2.5	84.6	73.3

2D, 2-dimensional; *AUC*, area under the curve; *CI*, confidence interval.

Table IV Predicting the need for an augment based on 3D bone loss measurements

Reviewer	AUC	95% CI	*P* value	Bone loss, mm	Sensitivity, %	Specificity, %
1	0.753	0.601-0.905	.017	3.6	71.0	80.0
2	0.740	0.576-0.904	.011	2.9	88.5	60.0
3	0.863	0.754-0.971	<.001	2.8	80.8	67.7

3D, 3-dimensional; *AUC*, area under the curve; *CI*, confidence interval.

Table V Augment utilization with posterior bone loss <2.5 mm

Reviewer	<2.5 mm, %	>2.5 mm, %	*P* value
1	70.0	77.4	.683
2	38.5	75.0	.024
3	35.3	83.3	.002

Table VI Augment utilization with posterior bone loss <3.0 mm

Reviewer	<3.0 mm, %	>3.0 mm, %	*P* value
1	68.8	80.0	.413
2	42.1	79.2	.013
3	40.0	85.7	.004

2 years. In a smaller series, Matsen and colleagues[25] retrospectively reviewed 71 anatomic shoulder arthroplasties that were performed with no regard for preoperative retroversion. Twenty-one patients had greater than 15° of retroversion postoperatively whereas the remaining 50 patients had less than 15° of retroversion. There were no differences in clinical or radiographic outcomes at 2 years.

Posterior subluxation was moderately and fairly associated with the plan for an augment in our cohort. Posterior subluxation is an important factor to consider when planning anatomic shoulder arthroplasty and is an important, though underappreciated, component of the B2 glenoid. The underlying pathophysiology of the posterior subluxation seen in primary glenohumeral arthritis is poorly understood.[10] However, it has been shown that mild posterior subluxation can be corrected with eccentric reaming. Gerber et al[10] reported on 23 shoulders with a minimum of 65% posterior subluxation treated with eccentric reaming and anatomic shoulder arthroplasty. With a mean preoperative retroversion of 18°, posterior subluxation was corrected in 21 of 23 shoulders, with improved clinical outcomes at a mean follow-up of 3.5 years.

Finally, augment size was moderately, positively correlated with the amount of bone loss on 3D imaging but not with 2D imaging. This is an important finding and highlights the benefit of 3D preoperative planning. The plan for a larger augment has previously been associated with increasing glenoid retroversion.[23] Additionally, the agreement between preoperative planning and actual implanted components at the time of surgery has been shown to be very high. Raiss et al[22] showed an 85% match in anatomic shoulder arthroplasty between the planned components and those used at the time of surgery. In the 58 cases where a posterior augment was used, the size was correctly predicted in 98% of cases.

Our study is not without limitations. First, we used BluePrint preoperative planning software to generate values for retroversion, inclination, and posterior subluxation. There are inherent differences between different planning software. We also selected various cutoffs for what was an acceptable position of the glenoid component. This was based on a current review of the literature and what we consider acceptable in our practice; however, we recognize that other surgeons may accept more or less than what we used in this study. We also present no postoperative outcomes and make no comment on the proposed clinical outcomes of using an augmented glenoid component in a Walch B2 glenoid.

Conclusion

The plan for a posterior augment in Walch B2 glenoids is better predicted with 3D imaging than with 2D

imaging, as 2D imaging may underestimate posterior bone loss. Additionally, use of a larger augment size is moderately correlated with posterior bone loss on 3D imaging but not 2D imaging. Standard 2D imaging may be limited in cases of posterior bone loss and 3D imaging may be beneficial for preoperative planning in Walch B2 glenoids.

Disclaimer

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