Impact of surgical variability on implant stability in stemless arthroplasty

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INTRODUCTION:

Bone mineral density (BMD) is a determinant of stemless shoulder implant stability [1], and can be extracted from computed tomography (CT) scans as part of preoperative planning.

However, there is often a discrepancy between the preoperatively planned resection cut and the reality of the operation theater, which can be impacted by the use of conventional or robotic instrumentation [1-3]. This discrepancy might affect the quality of the trabecular bone that is directly supporting and providing stability for a stemless implant. This study tested two hypotheses:

1. Robotic surgery increases the accuracy of a humeral head resection cut in shoulder arthroplasty relative to the plan.

2. This increased accuracy directly impacts the BMD, which is a primary source of stability for stemless TSA.

METHODS:

To address hypothesis 1 and compare the accuracy of the humeral head resection cut in conventional and robotic surgery, a cadaver study involving 69 matched-pair shoulders was conducted by 14 experienced surgeons. Preoperative CT scans were first acquired and used to plan anatomic and reverse shoulder arthroplasties using a surgical planner. One side of each pair was then randomly operated with conventional instrumentation and the other with a surgical robot. The same surgeon performed the operation on each side in a given pair. Postoperative CT scans were performed to visualize the resulting resections. Anatomic and reverse shoulder arthroplasty results were analyzed together. The accuracy of the conventional and robotic surgeries was finally evaluated by comparing the preoperative plan and actual resections.

To address hypothesis 2 and estimate the sensitivity of BMD to variability in humeral head resections, CT scans of 45 humeri were acquired with a BMD phantom (B-MAS200, Kyoto Kagaku, Kyoto, Japan) and were segmented in Mimics (Materialise, Leuven, Belgium) to create three-dimensional models with calibrated density information. The resection planning was performed and defined through the anatomical humeral neck. Surgical variation was then simulated by varying the resection plane inclination angle, retroversion angle, and height within the accuracy ranges measured in the cadaver study for the conventional instrumentation and for the robotic resections (Figure 1). A total of 100 resections were simulated for each bone following a Latin hypercube sampling within the variable distributions. The mean BMD was then computed for each simulated resection within the proximal trabecular volume below the resection cut using Matlab (Mathworks, Natick, MA, USA). The planned BMD and the finally achieved BMD were compared for the conventional instrumentation and robotic resections. Statistical analysis to compare surgical deviations was performed using a Wilcoxon test. BMD based on planned and surgically achieved resection were compared using correlation analysis and comparison of correlation.

RESULTS:

The accuracy of the inclination, version, and height was significantly improved in the robotic group compared to the conventional group ($p<0.05$) (Table 1).

The preoperative and postoperative BMD estimates were significantly correlated for conventional resections ($R^2=0.978$, SD_{err} = 5.04 mg/cm^3, $p<0.001$) and robotic resections (R^2 = 0.995, SD_{err} = 2.47 mg/cm^3, $p<0.001$). Discrepancy between the preoperative and postoperative BMD estimates (i.e. residual errors) were significantly reduced for robotic resections ($p < 0.001$), further emphasizing the benefit of improved accuracy of the surgery with respect to the planning (Table 2).

DISCUSSION AND CONCLUSION:

Resections made with a surgical robot were closer to the planned resection when compared to conventional instrumentation, and this improved the reliability of preoperative BMD estimates.

It must be noted that highly experienced shoulder surgeons performed the cadaveric surgeries, and the differences reported here may be greater with lower volume surgeons.

Surgical variability in humeral head resection impacts BMD at the implantation site, but the influence can be greatly minimized with the more precise robotic surgery. This finding may have key implications for future development of surgical planning tools, especially for implants with metaphyseal fixation such as stemless implants.

References

[1] Favre et al. *Clin Biomech,* 2016; 32:113-7; [2] Suter et al., *Arch Orthop Trauma Surg*, 2022; 142(11): 3141–3147; [3] Joyce *et al.*, *J Shoulder Elb Surg*, 2022; 31(8): 1674–1681.

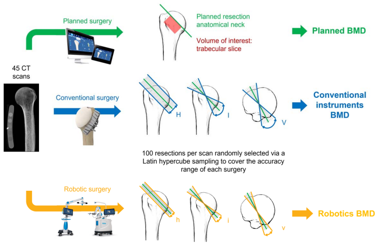

Figure 1. Bone mineral density (BMD) was computed for planned cases (*green*), and cases resulting from conventional (*blue*) and robotic (*yellow*) surgeries. Surgical variability in humeral head resection cut was simulated by varying height (h), inclination (i) and version (v) within the ranges measured for the conventional and robotic surgeries, and the influence on BMD was then computed.

Accuracy	Conventional surgery (18 TSA / 18 RSA)	Robotic surgery (16 TSA / 17 TSA)
Height (mm)	H = 2.6 ± 1.6	h = 1.2 ± 0.8
Inclination (°)	I = 5.5 ± 3.6	i = 3.7 ± 3.2
Version (°)	V = 10.7 ± 7.3	v = 3.9 ± 2.8

Table 1. Accuracy with conventional and robotic shoulder surgery between planned and actual humeral resection.

Relation between planned BMD and:	R^2	$SD_{residual\_error}$ mg/cm^3
BMD conventional instruments	0.978	5.04
BMD robotics	0.995	2.47

Table 2. Correlation between preoperative and postoperative bone density estimates for conventional and robotic surgeries.