EPiC Series in Health Sciences
Volume 8, 2026, Pages 89–93
Proceedings of The 25th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

Resection accuracy affects stemless shoulder implant stability

Ingmar Fleps[1], Kyle Snethen[1], Charlie Parduhn[1], Alex Miranda[1], Christine Mueri[2], Ghislain Maquer[2], Chloé Landry[3], Thomas Duquin[4], John Sperling[5], Taku Hatta[6], Jeff Bischoff[1], Philippe Favre[2]

[1]Zimmer Biomet, Warsaw, United States
[2]Zimmer Biomet, Winterthur, Switzerland
[3]Zimmer Biomet, Montreal, Canada
[4]UBMD Orthopaedics & Sports Medicine, Buffalo, United States
[5]Department of Orthopedic Surgery, Mayo Clinic, MN, United States
[6]Joint Surgery, Sports Clinic Ishinomaki, Ishinomaki, Japan

ingmar.fleps@zimmerbiomet.com, kyle.snethen@zimmerbiomet.com, charlie.parduhn@zimmerbiomet.com, alex.miranda@zimmerbiomet.com, christine.mueri@zimmerbiomet.com, ghislain.maquer@zimmerbiomet.com, chloe.landry@zimmerbiomet.com, trduquin@buffalo.edu, sperling.john@mayo.edu, t-hatta@jss-clinic.com, jeff.bischoff@zimmerbiomet.com, philippe.favre@zimmerbiomet.com

Abstract

Stemless TSA requires sufficient bone density to ensure appropriate implant stability, both of which can be impacted by surgical precision. While bone density surrounding a stemless humeral implant and implant size are the strongest predictors of implant stability, this study shows that implant positioning also impacts bone density and, hence, stability. The increased precision offered by robotic surgery relative to conventional surgery is shown here to reduce the variability in bone density around the implant, and may therefore improve the confidence in primary stability estimates of stemless TSA based on the surgical plan.

1 Introduction

Stemless humeral implants are used in total shoulder arthroplasty (TSA) for patient with sufficiently dense trabecular bone for support. Despite good clinical performances [1], reliably identifying poor-quality bone remains a challenge for surgeons [2]. Implanting a stemless implant in poor quality bone may result in implant loosening and a revision to a stemmed implant.

Surgical planning based on preoperative computed tomography (CT) scans is increasingly used to define the target resection plane and implant sizing [3]. The patient's bone mineral density (BMD) around the humeral implant could be extracted from these CT scans and used to predict implant micromotion, a surrogate for implant stability [4]. However, deviation from surgical planning may compromise the accuracy of preoperative BMD estimates, given its strong regional variation in the proximal humerus [5]. Even though robotic surgery generally provides higher resection accuracy [6] than conventional instrumentation, its impact on micromotion predictions and implant stability remains unclear.

This study measured deviations from planning using robotic and conventional surgeries (Analysis A) and evaluated the effect of these deviations on BMD and micromotion estimates (Analysis B) using cadaveric specimens.

2 Material and Methods

Analysis A (Figure 1) evaluated deviations from the surgical planning when using a surgical robot versus conventional instruments. Eighteen cadaveric humerus pairs (77.6±13.3 years, 12M/6F) underwent TSA, with one side randomly assigned to conventional instrumentation and the other to robotic surgery. All resections were planned on preoperative CT scans. Actual resections were measured on postoperative CT scans. The difference between planned and actual resections was computed in terms of height, inclination and version angles. Statistical differences between the two resection methods were evaluated for differences of the mean (Wilcoxon test) and the variance (F-test).

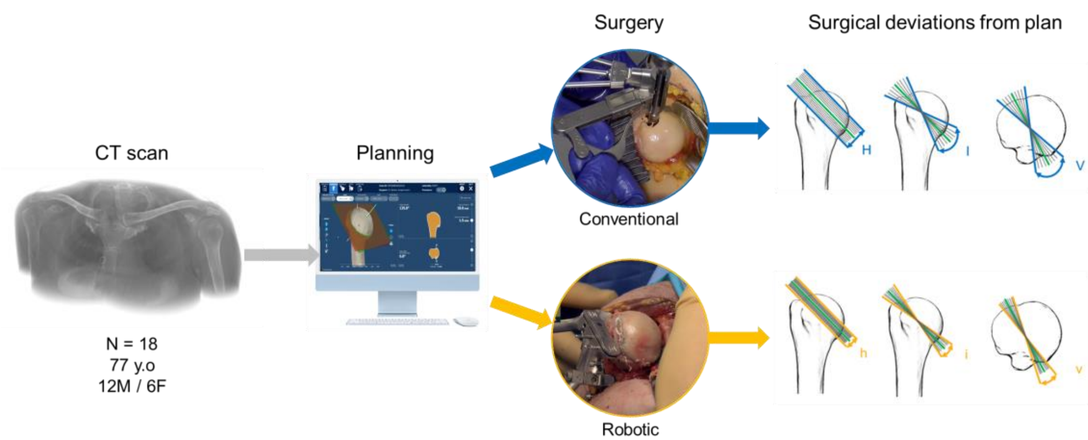

Figure 1. Analysis A evaluated the surgical deviations from the surgical planning when using conventional instrumentation versus robotic surgery, in terms of height (h), inclination (i) and version (v) angles.

Analysis B (Figure 2) determined the BMD-micromotion relationship for a given stemless implant. Thirty-two cadaveric humeri (74.8±9.0 years, 15M/17F) were CT scanned with a calibration phantom (BDC-3, QRM, Germany) and implanted with a stemless system. Each specimen was then radiographed to determine the implant position and tested with cyclic loads representative of daily activities (up to 107 % body weight), while implant micromotion relative to the bone was recorded via a stereo camera system. BMD around the anchor was extracted from the CT scans based on the location of the implant determined in the postoperative radiographs. A general linear model predicting implant micromotion as a function of BMD, anchor size, inclination angle, version angle and resection height (Micromotion model) was established to determine the most relevant parameters. Micromotion and BMD were log transformed for the general linear model to better satisfy the normality assumption. A hundred resections were simulated within the surgical deviation ranges from Analysis A and the resulting BMD values were measured. These BMD values were used in the general linear model generated in Analysis B to determine the corresponding micromotion range for each bone.

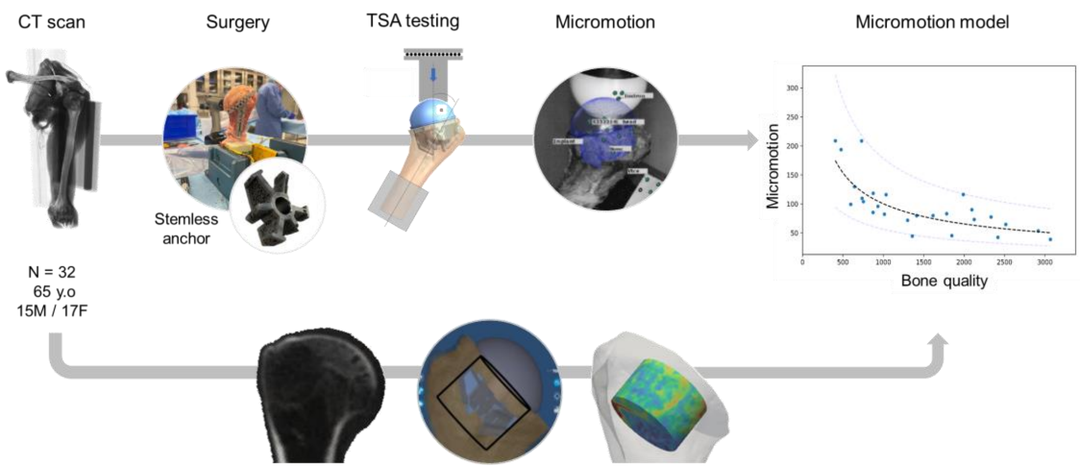

Figure 2. Analysis B established a model predicting implant micromotion as a function of BMD, anchor size, inclination angle, and resection height for a stemless implant in TSA.

3 Results

Analysis A: Surgical Deviations. Deviations in inclination, version, and height were significantly lower in robotic than conventional surgery ($p < 0.05$).

Mean deviations from planning with conventional surgery:
- Inclination: 5.5° (SD = 3.6)
- Version: 10.7° (SD = 7.3)
- Height: 2.6 mm (SD = 1.6)

Mean deviations from planning with robotic surgery:
- Inclination: 3.7° (SD = 3.2)
- Version: 3.9° (SD = 2.8)
- Height: 1.2 mm (SD = 0.8)

Analysis B: BMD-Micromotion Relationship. Mean BMD around the planned anchor location was found to be 40.5 mg/cm^3 (SD_{BMD} = 26.6) while the measured micromotions were averaging 98 µm (SD_{MIC} = 48.6). A general linear model accounting for BMD alone explained 54% of the variation in micromotion. Including anchor size improved the model, with 68% of the variation explained. Despite the remaining unexplained variation, predicted micromotions correlated significantly with measured values ($p < 0.001$). Including inclination angle and resection height did not improve the prediction.

Combined Analysis. Surgical deviations led to variations in BMD of 10.4 mg/cm^3 (39% of SD_{BMD}) with conventional surgery and 5.3 mg/cm^3 (20% of SD_{BMD}) with robotic surgery. Using these variations in BMD as input for the model established in Analysis B resulted in variations in micromotion of 22 µm (45% of SD_{MIC}) with conventional surgery and 13 µm (27% of SD_{MIC}) with robotic surgery.

4 Discussion

This study confirms that BMD is the strongest predictor of micromotion, explaining more than half of the observed variation, consistent with prior findings[4]. The inclusion of anchor size as a covariate further improved the model's predictive power.

Implant positioning significantly impacted outcomes, with robotic surgery resulting in half the variability in bone density and micromotion compared to conventional surgery. While conventional surgery produces acceptable outcomes in most cases, minimizing surgical variability - through robotics [6] or patient-specific instrumentation (PSI) [7] - could be critical for lower-density cases.

This pilot study lays the foundation for improving the micromotion model in future research. Beyond bone density and anchor size, factors such as degree of bone coverage by the head could influence implant micromotion and should be considered in subsequent models. Furthermore, alternative model types beyond GLM may enhance micromotion predictions.

Bone density thresholds can retrospectively discriminate between stable stemless cases and those requiring intraoperative revision with stemmed implants [8–10]. While thresholds offer simplicity, micromotion provides a more nuanced predictor of primary stability by incorporating factors such as implant size and surgical execution, and potentially implant design [11]. Estimation of implant micromotion based on preoperative BMD and precise surgical technique can help selecting suitable candidates for stemless TSA and optimize implant stability.

Future work to benchmark acceptable micromotion levels could involve micromotion experiments on paired humeri, implanting one side with a stemless and the other with a state-of-the-art stemmed system. Alternatively, validated computer simulations could compute micromotion for both implant types on identical bones, ensuring direct comparison under controlled condition [12].

References

[1] F. Schönweger, L.M. Oldrini, P. Feltri, G. Filardo, C. Candrian, Stemmed VS stemless total shoulder arthroplasty: a systematic review and meta-analysis, Arch. Orthop. Trauma Surg. 145 (2025) 1–10. https://doi.org/10.1007/s00402-024-05645-3.

[2] T. Hatta, K. Shinagawa, J. Kawakami, K. Kanazawa, T. Hayakawa, N. Yamamoto, K. Yamakado, A survey and biomechanical analysis of the feasibility of the thumb test for determining the cancellous bone quality for stemless shoulder prosthesis, J. Orthop. Surg. 31 (2023) 1–9. https://doi.org/10.1177/10225536231218869.

[3] N. Mehta, J.R. McCormick, G.E. Garrigues, Preoperative planning and its role in anatomic total shoulder arthroplasty, Semin. Arthroplast. JSES 34 (2024) 242–251. https://doi.org/10.1053/j.sart.2023.04.015.

[4] P. Favre, J. Seebeck, P.A.E. Thistlethwaite, M. Obrist, J.G. Steffens, A.R. Hopkins, P.A. Hulme, In vitro initial stability of a stemless humeral implant, Clin. Biomech. 32 (2016) 113–117. https://doi.org/10.1016/j.clinbiomech.2015.12.004.

[5] J.M. Reeves, T. Vanasse, C. Roche, G.S. Athwal, J.A. Johnson, K.J. Faber, G.D.G. Langohr, Regional apparent density correlations within the proximal humerus, JSES Int. 5 (2021) 525–531. https://doi.org/10.1016/j.jseint.2020.12.001.

[6] M. Vanderstappen, J.H.M. van Ochten, O. Verborgt, Robotics in arthroplasty: how good are they?, JSES Int. (2024) 4–9. https://doi.org/10.1016/j.jseint.2024.09.005.

[7] J.T. Rojas, B. Jost, R. Hertel, C. Zipeto, F. Van Rooij, M.A. Zumstein, Patient-specific instrumentation reduces deviations between planned and postosteotomy humeral retrotorsion and height in shoulder arthroplasty, J. Shoulder Elb. Surg. 31 (2022) 1929–1937. https://doi.org/10.1016/j.jse.2022.02.025.
[8] J.M. Levin, K. Rodriguez, B.A. Polascik, S. Zeng, E. Warren, A. Rechenmacher, J. Helmkamp, D.E. Goltz, J. Wickman, C.S. Klifto, T.E. Lassiter, O. Anakwenze, Simple preoperative radiographic and computed tomography measurements predict adequate bone quality for stemless total shoulder arthroplasty, J. Shoulder Elb. Surg. 31 (2022) 2481–2487. https://doi.org/10.1016/j.jse.2022.05.008.
[9] J.M. Gregory, J. Siahaan, M. Urvoy, Preoperative metaphyseal cancellous bone density is associated with intraoperative conversion to stemmed total shoulder arthroplasty, JSES Rev. Reports, Tech. 3 (2023) 285–288. https://doi.org/10.1016/j.xrrt.2023.01.009.
[10] D. Ritter, P.J. Denard, P. Raiss, C.A. Wijdicks, S. Bachmaier, Preoperative 3-dimensional computed tomography bone density measures provide objective bone quality classifications for stemless anatomic total shoulder arthroplasty, J. Shoulder Elb. Surg. 33 (2024) 1503–1511. https://doi.org/10.1016/j.jse.2023.11.005.
[11] C. Quental, J. Folgado, M. Comenda, J. Monteiro, M. Sarmento, Primary stability analysis of stemless shoulder implants, Med. Eng. Phys. 81 (2020) 22–29. https://doi.org/10.1016/J.MEDENGPHY.2020.04.009.
[12] G. Maquer, C. Mueri, A. Henderson, J. Bischoff, P. Favre, Developing and Validating a Model of Humeral Stem Primary Stability , Intended for In Silico Clinical Trials, Ann. Biomed. Eng. (2024). https://doi.org/10.1007/s10439-024-03452-w.