The Glenoid Vault: Anatomic Cadaver Study Exploring Alternative Solutions for Glenoid Implant Survival in Total Shoulder Arthroplasty

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Introduction

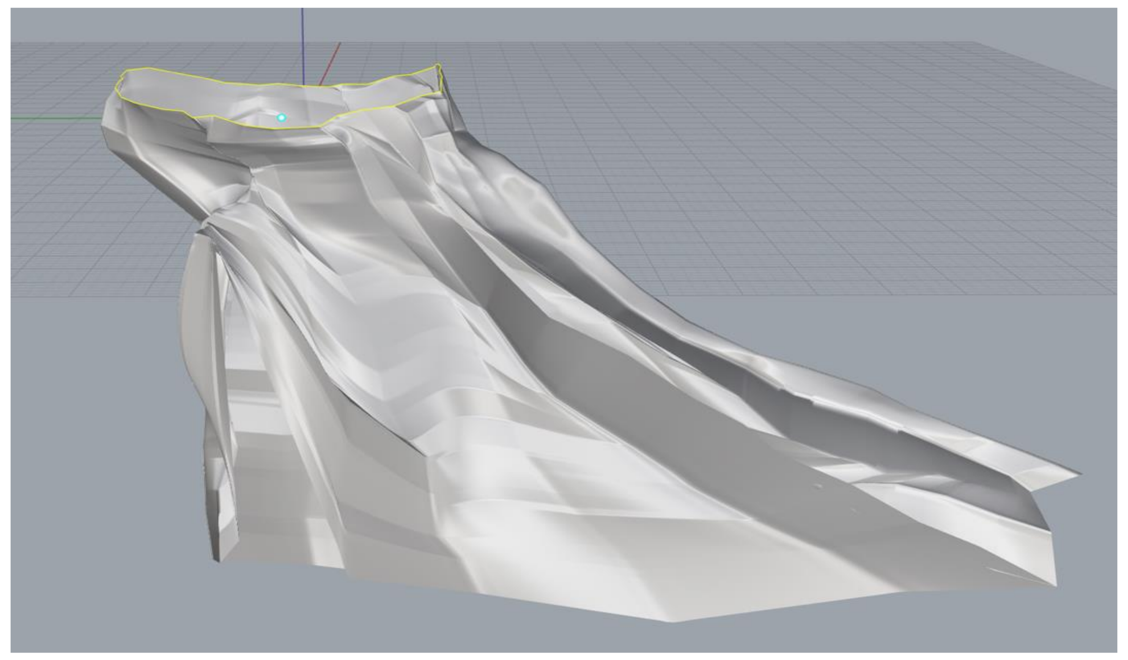
Total shoulder arthroplasty is a common surgical procedure indicated for arthritis of the glenohumeral joint[12]. First introduced by Emile Péan in 1893 as the platinum-rubber shoulder arthroplasty for the treatment of tuberculous arthritis, the concept of total shoulder prothesis has undergone numerous developments over the past century[1]. Péan's prothesis was succeeded by an attempted total shoulder arthroplasty in the 1950s using acrylic components, but was unsuccessful due to lack of material durability[2]. This attempt was eventually followed by the first modern anatomic shoulder replacement performed by Charles Neer in 1974, which featured a vitallium humeral component and polyethylene glenoid component[3]. Although more successful than previous approaches, Neer's prosthesis suffered from high failure rates due to glenoid loosening[2]. Despite its high failure rates, it ultimately laid the foundation for the development of the modern total shoulder arthroplasty. Today, anatomic total shoulder arthroplasty features the implantation of a stemmed metal, convex articular component for the head of the humerus and a concave polyethylene "cup" in the proximal glenoid, replicating the anatomical arrangement of the glenohumeral joint.

Although this surgical procedure is highly successful in restoring the function of the glenohumeral joint and relieving pain associated with glenohumeral degeneration, it is not free of post-operative complications[4,13,14,16]. Prosthetic loosening accounts for 39% of total shoulder arthroplasty complications, with glenoid component loosening being responsible for 32% of all complications[4]. Glenoid component loosening is one of the most common causes of total shoulder arthroplasty failure, and is associated with symptoms such as pain, stiffness, material failure, wear and joint instability[5,6,7,8,9,12]. Further, revision surgery is indicated in most cases of glenoid component loosening[5,10,11,15]. The common problem of glenoid component loosening is one that has not been fully resolved since the development and application of Neer's prosthesis – thus, there is a clear and enduring need to further explore the glenoid's morphology and discover alternative methods for stabilization of the glenoid component in total shoulder arthroplasty.

Objectives

Through examination of the anatomy of the glenoid vault as it pertains to glenoid component implantation, there is potential to better understand the cause of glenoid component loosening and craft new approaches to ensure the stability and longevity of the implant. While many anatomic studies have been conducted to quantify the superficial features of the glenoid, fewer have investigated its internal spatial composition in both a qualitative and quantitative manner – thus, digitization of the glenoid and its surrounding scapular structures using our study's protocol has the potential to yield novel information about its overall morphology and capacity for modification[17-25]. Quantification and characterization of the glenoid vault will ultimately provide valuable insight into how to improve the success rate of total shoulder arthroplasty, and may provide information that can help lay the groundwork for the development of novel techniques for other procedures using similar glenoidal implants.

Figure 1. Three-D Model of the Glenoid and Associated Scapular Structures.



Methods

A Microscribe G2 Digitizer and Rhinoceros 3-D imaging software were used to digitize the glenoids of 70 cadaveric scapulae from the Cleveland Museum of Natural History's osteological collection. Three-dimensional models were manually constructed for each specimen using over 400 unique data points. Measurements were performed on the digitized scapulae using Rhinoceros' native analysis functions. The ideal positioning for achieving maximal cylinder diameter & best fit was determined for 5, 10 and 15 millimeter cylinders.

Figure 2. Top-down View of the Glenoid Vault The colored circles represent the varying cylinder depths: green = 5 mm, purple = 10 mm, red = 15 mm. The colored dots contained within each circle represent the center of each respective cylinder. The cyan point depicts the glenoid center. The colored lines from the glenoid center to the cylinder centers represent the distance between the respective points.

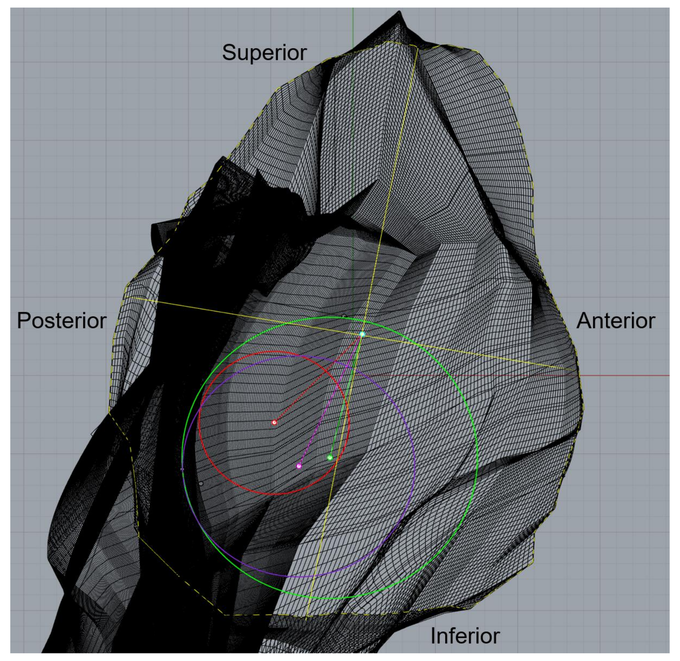
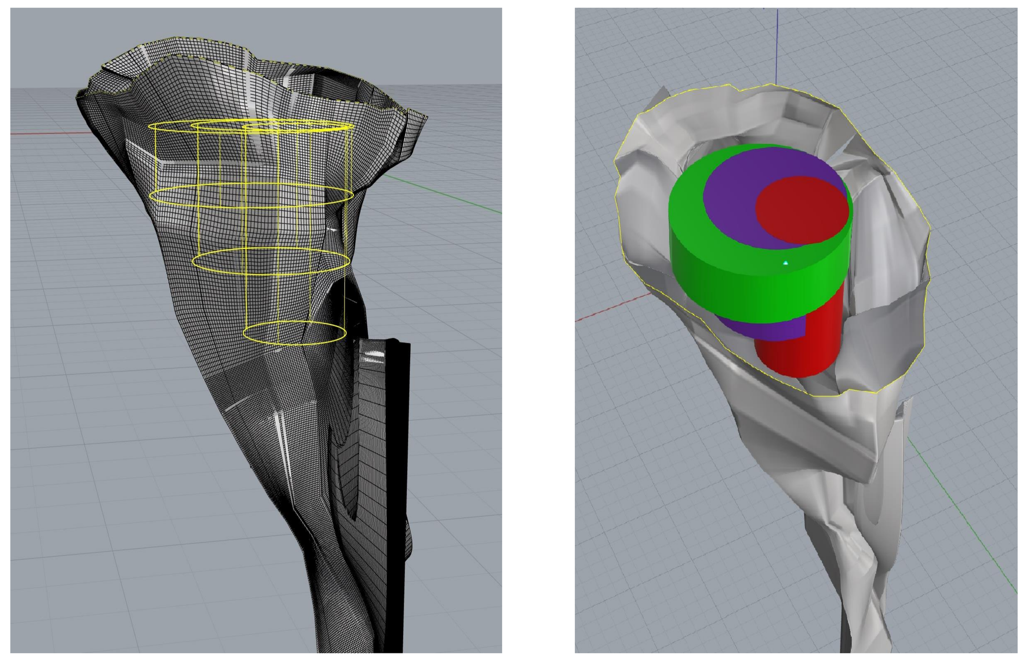


Figure 3. View from Superior End of Glenoid Showcasing Best-fit Cylinder Placement.



	Average Maximum Cylinder Diameter (mm)	Average Distance from Glenoid Center to Cylinder Center (mm)	Angle from Y-axis (Inferior) to Cylinder Center	Average Maximum Cylinder Volume (mm^3)
5 mm Depth Cylinder (Male)	22.35 ± 2.93	5.40 ± 1.78	-8.76 ± 18.11	1995.37 ± 534.29
10 mm Depth Cylinder (Male)	17.21 ± 3.48	7.76 ± 2.84	-5.94 ± 15.12	2418.60 ± 999.18
15 mm Depth Cylinder (Male)	13.32 ± 3.14	7.52 ± 3.92	-10.62 ± 21.67	2237.56 ± 1064.42
5 mm Depth Cylinder (Female)	16.55 ± 1.96	6.00 ± 1.92	-8.69 ± 11.67	1050.69 ± 226.53
10 mm Depth Cylinder (Female)	11.15 ± 1.82	7.45 ± 3.04	-2.46 ± 11.30	1001.53 ± 320.14
15 mm Depth Cylinder (Female)	8.48 ± 1.91	8.36 ± 3.49	-5.56 ± 13.08	863.66 ± 345.47

Figure 4. Key Results

Results

The average maximum diameter for 5, 10 and 15 millimeter depth cylinders was 22.35 ± 2.93, 17.21 ± 3.48 and 13.32 ± 3.14 mm respectively for male specimens, and 16.55 ± 1.96, 11.15 ± 1.82 and 8.48 ± 1.91 mm respectively for female specimens. The average distance from the glenoid center to the cylinder center for 5, 10 and 15 mm depth cylinders was 5.40 ± 1.78, 7.76 ± 2.84 and 7.52 ± 3.92 mm respectively for males, and 6.00 ± 1.92, 7.45 ± 3.04 and 8.36 ± 3.49 mm respectively for females. In male specimens, the average angle from the vertical axis to the cylinder center was -8.76 ± 18.11, -5.94 ± 15.12, -10.62 ± 21.67 degrees in the inferior-posterior quadrant for 5, 10 and 15 mm depths respectively. In female specimens, the average angle from the vertical axis to the cylinder center was -8.69 ± 11.67, -2.46 ± 11.30, -5.56 ± 13.08 degrees in the inferior-posterior quadrant for 5, 10 and 15 mm depths respectively. In male specimens, the average maximum cylinder volume accommodated by this region was 1995.37 ± 534.29, 2418.60 ± 999.18 and 2237.56 ± 1064.42 mm^3 for 5, 10 and 15 mm depth cylinders respectively. In female specimens, the average maximum cylinder volume accommodated by this region was 1050.69 ± 226.53, 1001.53 ± 320.14 and 863.66 ± 345.47 mm^3 for 5, 10 and 15 mm depth cylinders respectively.

Conclusion

- This study presents novel findings pertaining to glenoid morphology through both 3-D digitization and the quantitative and qualitative analysis of a newly characterized modification site.
- Using this information, innovative surgical techniques, reaming strategies and glenoid implant designs can be developed.
- This region has not been quantified or characterized in this manner previously, and thus provides an opportunity for guided exploration into alternative approaches to glenoidal prosthesis fixation in total shoulder arthroplasty and related procedures.
- Through the development of alternatives to traditional approaches to total shoulder arthroplasty and related surgical procedures involving the glenohumeral joint, there is potential to discover solutions that minimize–or perhaps even eliminate–the occurrence of post-operative glenoid implant loosening in these surgical procedures.

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