Impact of 3D CT Reconstructed Deltoid Size, Shape, and Volume Measurements on Active Range of Motion Before and After Anatomic and Reverse Total Shoulder Arthroplasty

William Reuben Aibinder[1], Josie A Elwell, Hamidreza Rajabzadeh-Oghaz, Bradley S Schoch, Bruno Borralho Gobbato[2], Anshuman Singh[3], David Berry, Vikas Kumar[4], Christopher Roche
[1]University of Michigan, [2]IOT Jaragua, [3]Garfield Specialty Center, [4]Exactech Inc.

INTRODUCTION:

The deltoid is the primary elevator in the shoulder, and yet, few studies have quantified the 3-D size and shape of the muscle and no studies have correlated those measurements to active range of motion after anatomic (aTSA) and/or reverse (rTSA) total shoulder arthroplasty in any statistically/scientifically relevant manner. The goal of this study is to quantify the 3D CT reconstructed deltoid size and shape from 960 shoulder arthroplasty patients and determine the relationship of those image parameters to active range of motion measurements 2-years after aTSA and rTSA.

METHODS:

Preoperative CT images from 960 patients (584F/374M/2Unk), 700 rTSA (445F/253M/2Unk) and 260 aTSA (139F/121M) treated with a single platform shoulder arthroplasty prosthesis (Equinoxe; Exactech, Inc., Gainesville, FL) were analyzed in this study. A machine learning (ML) framework was used to segment the deltoid muscle and quantify 7 different muscle characteristics of size, shape, and volume. All patients had 2-year minimum follow-up, average = 37.8 ± 14.0 months; rTSA: 37.8, aTSA: 37.9). For all patients, active abduction and forward elevation were quantified pre-operatively and at latest follow-up. A multivariate analysis was conducted to compare deltoid image data associated with each aTSA and rTSA patient when classified by 3 different clinically relevant criteria: 1) bottom 25% or top 75% of preoperative abduction/forward elevation, 2) whether each patient achieved (or failed to achieve) patient acceptable symptomatic state (PASS) at latest follow-up for abduction/forward elevation, and 3) whether each patient achieved (or failed to achieve) minimally clinically important difference (MCID) improvement for abduction/forward elevation.

RESULTS:

The multivariate regression analysis identified several deltoid image measurements relevant to pre-operative (Table 1), post-operative (Table 2, PASS), and pre-to-post-operative measurements (Table 3, MCID) of abduction and forward elevation. Specifically, as described in Table 1, deltoid flatness (p=0.042) was identified for pre-operative forward elevation for aTSA patients and deltoid volume normalized by scapular bone volume (p=0.042) was identified for pre-operative abduction for rTSA patients. As described in Table 2, deltoid volume (p=0.030) was identified for achieving PASS for active abduction for aTSA patients. As described in Table 3, deltoid volume normalized by scapular bone volume was identified for achieving MCID for forward elevation (p=0.032) and abduction (p=0.041) for rTSA patients.

DISCUSSION AND CONCLUSION:

The results of this 960 patient shoulder arthroplasty study identified multiple 3D deltoid size, shape, and volume measurements that were statistically relevant to achieving clinically relevant active range of motion thresholds after aTSA and rTSA. Such data is useful to help better understand the relationship between deltoid morphology and functional performance after shoulder arthroplasty and the identification of specific clinically relevant deltoid measurements can be used to inform development of future clinical decision support tools which utilize CT image data to improve treatment decision making.

Table 1. Multivariate Analysis of Deltoid Image Size, Shape, and Volume Measurements Associated with aTSA and rTSA Patients who Failed to Achieve 25th Percentile of the Cohort's Pre-operative Forward Elevation (80°) and Abduction (60°) as Compared to Patients Exceeded this Pre-operative Active Range of Motion Threshold.

aTSA	Deltoid Image Measurement	Did not Achieve	Did Achieve	P-Value (univariate)	P-Value (multivariate)
Preop Forward Elevation (<80°)	Volume (cm³)	320.19 ± 110.98	360.31 ± 121.05	0.053	
	Volume Normalized by Scapular Volume	3.75 ± 0.67	3.87 ± 0.64	0.352	
	Flatness	0.45 ± 0.03	0.46 ± 0.04	0.018	**0.042**
	Max Deltoid Width in Sagittal Plane (mm)	163.2 ± 16.51	164.16 ± 14.64	0.744	
	Max Deltoid Length in Sagittal Plane (mm)	127.63 ± 21.87	133.85 ± 19.95	0.117	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.647	
	Volume Normalized by Age and Gender	1.02 ± 0.16	1.03 ± 0.15	0.686	
Preop Abduction (<60°)	Volume (cm³)	296.45 ± 99.91	362.13 ± 121.16	**0.002**	0.094
	Volume Normalized by Scapular Volume	3.57 ± 0.68	3.89 ± 0.63	**0.020**	0.418
	Flatness	0.45 ± 0.04	0.46 ± 0.04	0.082	
	Max Deltoid Width in Sagittal Plane (mm)	162.45 ± 14.44	164.17 ± 15	0.542	
	Max Deltoid Length in Sagittal Plane (mm)	127.02 ± 21.94	133.7 ± 20.05	0.117	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.696	
	Volume Normalized by Age and Gender	0.98 ± 0.16	1.04 ± 0.15	**0.050**	*.
rTSA	**Deltoid Image Measurement**	**Did not Achieve**	**Did Achieve**	**P-Value (univariate)**	**P-Value (multivariate)**
Preop Forward Elevation (<80°)	Volume (cm³)	303.13 ± 94.86	328.86 ± 109.42	**0.001**	0.437
	Volume Normalized by Scapular Volume	3.62 ± 0.66	3.77 ± 0.65	0.003	0.078
	Flatness	0.47 ± 0.04	0.47 ± 0.04	0.110	
	Max Deltoid Width in Sagittal Plane (mm)	157.65 ± 15.4	159.6 ± 15.69	0.109	
	Max Deltoid Length in Sagittal Plane (mm)	131.23 ± 19.73	135.37 ± 20.16	**0.008**	0.191
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.032	
	Volume Normalized by Age and Gender	1 ± 0.18	1.04 ± 0.17	**0.010**	*.
Preop Abduction (<60°)	Volume (cm³)	303.73 ± 91.87	328.51 ± 110.32	**0.002**	0.395
	Volume Normalized by Scapular Volume	3.58 ± 0.64	3.79 ± 0.65	**0.000**	**0.042**
	Flatness	0.47 ± 0.04	0.47 ± 0.04	0.422	
	Max Deltoid Width in Sagittal Plane (mm)	157.99 ± 15.38	159.47 ± 15.77	0.234	
	Max Deltoid Length in Sagittal Plane (mm)	133.61 ± 19.99	134.02 ± 20.29	0.798	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	**0.002**	0.412
	Volume Normalized by Age and Gender	0.99 ± 0.18	1.05 ± 0.17	**<0.001**	*.

*Note that a collinearity check removed volume normalized by Age and Gender from the multivariate analysis.

Table 2. Multivariate Analysis of Deltoid Image Size, Shape, and Volume Measurements Associated with aTSA and rTSA Patients who Failed to Achieve 2-year Minimum PASS for Forward Elevation (130°) and Abduction (104°) as Compared to Patients Exceeded PASS.

aTSA	Deltoid Image Measurement	Did not Achieve	Did Achieve	P-Value (univariate)	P-Value (multivariate)
2yr Min Forward Elevation PASS (130°)	Volume (cm³)	323.39 ± 98.32	351.17 ± 121.26	0.211	
	Volume Normalized by Scapular Volume	3.8 ± 0.65	3.84 ± 0.65	0.781	
	Flatness	0.45 ± 0.03	0.46 ± 0.04	0.513	
	Max Deltoid Width in Sagittal Plane (mm)	161.05 ± 13.52	163.82 ± 15.04	0.354	
	Max Deltoid Length in Sagittal Plane (mm)	128.09 ± 22.01	132.89 ± 20.37	0.316	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.302	
	Volume Normalized by Age and Gender	1.02 ± 0.16	1.03 ± 0.15	0.664	
2yr Min Abduction PASS (104°)	Volume (cm³)	302.17 ± 80.85	353.24 ± 122.22	**0.004**	**0.030**
	Volume Normalized by Scapular Volume	3.66 ± 0.72	3.86 ± 0.64	0.158	
	Flatness	0.46 ± 0.04	0.46 ± 0.04	0.422	
	Max Deltoid Width in Sagittal Plane (mm)	160.23 ± 12.99	164.05 ± 15.11	0.160	
	Max Deltoid Length in Sagittal Plane (mm)	130.87 ± 18.27	132.54 ± 20.9	0.660	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.209	
	Volume Normalized by Age and Gender	0.99 ± 0.19	1.03 ± 0.15	0.338	
rTSA	**Deltoid Image Measurement**	**Did not Achieve**	**Did Achieve**	**P-Value (univariate)**	**P-Value (multivariate)**
2yr Min Forward Elevation PASS (130°)	Volume (cm³)	318.19 ± 96.05	318.1 ± 106.2	0.992	
	Volume Normalized by Scapular Volume	3.7 ± 0.65	3.73 ± 0.66	0.546	
	Flatness	0.47 ± 0.05	0.47 ± 0.04	0.854	
	Max Deltoid Width in Sagittal Plane (mm)	159.26 ± 14.6	158.77 ± 15.87	0.726	
	Max Deltoid Length in Sagittal Plane (mm)	131.61 ± 18.55	134.95 ± 20.5	0.062	
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.633	
	Volume Normalized by Age and Gender	1.02 ± 0.18	1.03 ± 0.17	0.695	
2yr Min Abduction PASS (104°)	Volume (cm³)	290.83 ± 94.85	328.01 ± 105.2	**<0.001**	0.304
	Volume Normalized by Scapular Volume	3.59 ± 0.65	3.77 ± 0.66	**0.003**	0.166
	Flatness	0.47 ± 0.04	0.47 ± 0.04	0.559	
	Max Deltoid Width in Sagittal Plane (mm)	154.97 ± 14.16	160.32 ± 15.83	**<0.001**	0.067
	Max Deltoid Length in Sagittal Plane (mm)	131.49 ± 19.8	135.09 ± 20.14	**0.047**	0.566
	Sphericity	0.45 ± 0.03	0.46 ± 0.03	0.070	
	Volume Normalized by Age and Gender	1 ± 0.17	1.04 ± 0.18	**0.031**	*.

*Note that a collinearity check removed volume normalized by Age and Gender from the multivariate analysis.

Table 3. Multivariate Analysis of Deltoid Image Size, Shape, and Volume Measurements Associated with aTSA and rTSA Patients who Failed to Achieve 2-year Minimum Pre-to-Post-operative MCID Improvement for Forward Elevation (16°) and Abduction (13°) as Compared to Patients Exceeded MCID.

aTSA	Deltoid Image Measurement	Did not Achieve	Did Achieve	P-Value (univariate)	P-Value (multivariate)
2yr Min Forward Elevation MCID (16°)	Volume (cm³)	366.81 ± 125.99	341.65 ± 116.14	0.169	
	Volume Normalized by Scapular Volume	3.96 ± 0.68	3.8 ± 0.63	0.115	
	Flatness	0.46 ± 0.04	0.46 ± 0.04	0.767	
	Max Deltoid Width in Sagittal Plane (mm)	163.74 ± 13.65	163.67 ± 15.37	0.974	
	Max Deltoid Length in Sagittal Plane (mm)	130.56 ± 17.32	132.81 ± 21.53	0.413	
	Sphericity	0.46 ± 0.03	0.45 ± 0.03	0.106	
	Volume Normalized by Age and Gender	1.06 ± 0.16	1.02 ± 0.15	0.128	
2yr Min Abduction MCID (13°)	Volume (cm³)	373.25 ± 133.08	341.15 ± 114.4	0.120	
	Volume Normalized by Scapular Volume	3.99 ± 0.7	3.8 ± 0.63	0.074	
	Flatness	0.46 ± 0.03	0.46 ± 0.04	0.700	
	Max Deltoid Width in Sagittal Plane (mm)	163.2 ± 14.12	163.81 ± 15.18	0.787	
	Max Deltoid Length in Sagittal Plane (mm)	130.66 ± 16.91	132.42 ± 21.5	0.538	
	Sphericity	0.46 ± 0.03	0.45 ± 0.03	0.139	
	Volume Normalized by Age and Gender	1.06 ± 0.16	1.02 ± 0.15	0.105	
rTSA	**Deltoid Image Measurement**	**Did not Achieve**	**Did Achieve**	**P-Value (univariate)**	**P-Value (multivariate)**
2yr Min Forward Elevation MCID (16°)	Volume (cm³)	337.51 ± 106.23	313.01 ± 102.77	**0.016**	0.940
	Volume Normalized by Scapular Volume	3.86 ± 0.61	3.68 ± 0.66	**0.002**	**0.032**
	Flatness	0.47 ± 0.04	0.47 ± 0.04	0.429	
	Max Deltoid Width in Sagittal Plane (mm)	158.58 ± 15.02	159.09 ± 15.73	0.724	
	Max Deltoid Length in Sagittal Plane (mm)	127.17 ± 19.56	133.22 ± 20.09	**0.037**	0.244
	Sphericity	0.46 ± 0.02	0.45 ± 0.03	0.150	
	Volume Normalized by Age and Gender	1.06 ± 0.16	1.02 ± 0.18	**0.003**	*.
2yr Min Abduction MCID (13°)	Volume (cm³)	335.85 ± 109.61	315.36 ± 102.25	0.056	
	Volume Normalized by Scapular Volume	3.89 ± 0.64	3.68 ± 0.65	**0.001**	**0.041**
	Flatness	0.47 ± 0.04	0.47 ± 0.04	0.784	
	Max Deltoid Width in Sagittal Plane (mm)	158.74 ± 15.4	159.22 ± 15.69	0.758	
	Max Deltoid Length in Sagittal Plane (mm)	136.01 ± 20.59	133.91 ± 19.99	0.301	
	Sphericity	0.46 ± 0.02	0.45 ± 0.03	**0.004**	0.352
	Volume Normalized by Age and Gender	1.07 ± 0.16	1.02 ± 0.17	**0.001**	*.

*Note that a collinearity check removed volume normalized by Age and Gender from the multivariate analysis.