Analysis of glenohumeral joint intraarticular pressure measurements in volume-limited MR arthrograms in patients with shoulder-instability compared to a control group[☆]

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ABSTRACT

Purpose: Compare intraarticular pressure of the glenohumeral joint in patients with and without shoulder instability after a volume-limited arthrogram.

Materials and methods: Patients aged 18–45 years with shoulder instability or pain were included. After injecting 10 cc of contrast-mixture, intraarticular pressure was recorded using an arterial-line pressure-transducer connected to a portable monitor.

Results: 14/16 (86%) patients were included – 7/14 (50%) had instability. Post-injection pressure measurement averaged 59.9 ± 44.0 mmHg (range 15–181). Instability patients averaged 60.8 ± 37.6 (range 15–117) versus 41.9 ± 14.0 mmHg (range 30–64) for non-instability ($p > 0.1$).

Conclusion: Glenohumeral pressure measurements are variable when utilizing standardized volume-limited arthrograms.

1. Introduction

Historically, intraarticular pressure measurements during shoulder arthrograms were utilized to assist in the diagnosis of various shoulder pathologies.^{1–3} More recently, there has been a renewed interest in the potential diagnostic value of measuring capsular area on MRAs as well as the use of a pressure-limited arthrogram prior to obtaining a shoulder MRA. Two recent studies have identified increased posterior capsular area measurements on MRA to be significantly associated with the diagnosis of posterior shoulder instability.^{4,5} However, these results are limited by current standard volume-limited arthrography techniques.⁴ The method of performing a volume-limited MRA may create situations where the volume of contrast injected leads to over- or under-estimation of the capsular area measurements due to variability in

patient size, joint morphology, or other intrinsic capsular characteristics. Pressure-limited arthrography may be a more effective technique than volume-limited arthrography in patients with shoulder instability to account for this patient variability.⁴ However, prior to evaluating pressure-limited arthrography for shoulder MRA, it is imperative that a reproducible technique is established for both intraarticular pressure measurement, and also the range of intraarticular pressures on volume-limited arthrograms.

The purpose of this study to present an accurate, reproducible method using a simple setup with standard arterial line equipment that can measure the glenohumeral joint intraarticular pressure in volume-limited arthrograms. In addition, we intend to analyze the effects of patient demographics and morphology as they pertain to the intraarticular pressure of the glenohumeral joint, and hypothesize that

Abbreviations: MRI, magnetic resonance imaging; MRA, magnetic resonance arthrogram/arthrography; IRB, institutional review board; CT, computed tomography; BMI, body mass index; VAS, visual analogue scale; ROC, Receiver Operating Characteristic

[☆] This study was approved by the Eisenhower Army Medical Center Institutional Review Board under the project #: 1704061–1. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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they will be variable in patients with and without shoulder instability.

2. Materials and methods

This is an institutional review board (IRB)-approved, prospective, observational, comparative study at a single institution. Over a 12-month period (October 2017–2018), patients aged 18–45 years presenting to the orthopaedic clinic with history and physical examination findings consistent with shoulder instability who did not already have advanced imaging of the shoulder (CT arthrogram, MRI, or MRA) were eligible for inclusion. Additionally, patients with a diagnosis other than shoulder instability who did not have any advanced imaging were also eligible for inclusion as a control group. All treating providers were orthopaedic surgeons. Patients < 18 or > 45 years old, with a history of prior ipsilateral shoulder surgery, a rotator cuff tear, degenerative arthritis, adhesive capsulitis, diagnosis of any collagen or connective tissue disorder, pregnancy, incarceration, active mental disability, contraindication to MRI, or those that had already received an MRA for the present issue were excluded.

Informed consent was obtained and a standardized arthrogram was performed as described below in the technique section. Patients proceeded immediately to the MRI scanner after the arthrogram. Additional data points collected include age, sex, laterality, height, weight, body mass index (BMI), absence/presence of instability, pre- and post-arthrogram Visual Analog Scale (VAS) scores, diagnosis at the time of indication for MRA, and if subsequent surgery was performed.

Power analysis *a priori* demonstrated that a minimum of 12 arthrograms would be required to verify that a minimum statistically significant difference of 17.0 mmHg exists in the instability group versus non, or neutrality. Levels for the power analysis were set at 0.80 with an alpha of 0.05 demonstrating significance. Analyses were performed to determine variability in pressure measurement in patients with and without a diagnosis of instability, as well as to determine any associations between patient demographics and pressures measurements obtained utilizing the paired Student t-test, two-tailed Fisher exact test, and multivariate regression analysis.

2.1. Pressure measurement of volume-limited arthrogram technique

All shoulder arthrograms were performed by a single fellowship-trained musculoskeletal radiologist. Patients were positioned supine in the arthrogram suite. The affected extremity was positioned in neutral shoulder flexion at 0° of adduction in a position of maximal external rotation. An anterior entry site was selected using fluoroscopic guidance and marked. The area was prepped and draped in a sterile fashion. The superficial soft tissue was locally anesthetized with a small amount of 1% lidocaine without epinephrine (Fig. 1). A 22-gauge spinal needle was introduced using the rotator interval method into the glenohumeral joint under intermittent fluoroscopic guidance (Fig. 2). A small test injection of 1 mL of 1% lidocaine was performed to confirm smooth flow. One milliliter of Ultravist contrast (Bayer HealthCare, Berlin, Germany) was injected to confirm correct placement with imaging (Fig. 3).

A syringe containing a mixture of 0.1 mL of Magnevist gadolinium contrast (Bayer HealthCare, Berlin, Germany), 10 mL of normal saline, and 10 mL of 1% lidocaine was obtained and connected to a three-way stopcock. Tubing was connected to another port of the three-way stopcock and flushed with the gadolinium mixture. The free end of the tubing was connected to the intraarticular needle. A sterile disposable arterial line pressure transducer (Transpac IV pressure transducer; ICU Medical, San Clemente, CA) was connected to a 1 L intravenous fluid bag of 0.9% normal saline placed within a pressure bag that was inflated to 150 mmHg. The arterial line pressure transducer was flushed with the normal saline from the bag and attached to the third port of the three-way stopcock (Fig. 4).

The arterial line pressure transducer was connected to a portable

Fig. 1. The anterior shoulder is prepped and draped in a sterile fashion, and the area is locally anesthetized after confirmation of location with fluoroscopic guidance.

transport monitor (GE CARESCAPE Monitor B450; GE Healthcare, Chicago, IL). The system was zeroed, by turning a stopcock of the arterial line pressure transducer open to the air. Then, 8 mL of the mixture with gadolinium contrast were injected into the glenohumeral joint (Fig. 5).

Immediately after the completion of the 10 cc injection, the three-way stopcock valve was turned to create continuity between the intraarticular needle and the arterial line pressure transducer. A pressure measurement was obtained immediately.

3. Results

Sixteen patients were included over a 12-month period. One patient was excluded due to findings of degenerative changes on MRA that were not readily identifiable with pre-enrollment radiographs of the

Fig. 2. A 22-gauge spinal needle is advanced into the glenohumeral joint with fluoroscopic guidance.

shoulder. A second patient was excluded due to error in technique during the arthrogram, leaving 14/16 (86%) patients for analysis (Table 1).

There were 12/14 (86%) male and 2/14 (14%) female patients with an average age of 28.4 ± 5.2 years (range 22–38). Average BMI was $28.4 \pm 3.8 \text{ kg/m}^2$ (range 23.0–35.2). 7/14 (50%) patients had pre-imaging diagnoses of instability (5/7 anterior, 1/7 posterior, 1/7 multidirectional) while 7/14 (50%) had other diagnoses (4/7 biceps tendinopathy, 3/7 acromioclavicular (AC) joint arthritis). Average post-injection pressure measurement was $59.9 \pm 44.0 \text{ mmHg}$ (range 15–181). Average pre- and post-VAS pain scores were 3.3 ± 2.4 (range 0–8) and 2.2 ± 2.8 (range 0–8), respectively. There were no complications related to the arthrogram procedure. All instability patients had labral tears without capsular injury identified at the time of diagnostic arthroscopy or on MRA. It should be noted that patient #4 (Table 1) received his arthrogram 1-week post-injury and it is speculated that the resultant remaining hemarthrosis caused the pressure measurement to be significantly elevated post-injection (181 mmHg). If this patient is excluded, the average pressure measurement for the remaining study group as a whole is 60.8 ± 37.6 (range 15–117).

3.1. Statistical analysis

Demographic differences (Table 2) were observed between the instability group and the non-instability group with the former being significantly younger ($p < 0.03$). There were no other differences between the two groups.

A multivariate regression analysis was performed to determine the impact of study variables on the pressure measurement results while excluding patient #4. None of the independent variables in this model could account for the recorded pressure measurements (Adjusted R square 0.80, $p > 0.08$, Table 3).

Fig. 3. Intraarticular glenohumeral joint positioning is confirmed with injection of 1 cc of contrast.

4. Discussion

We describe a simple technique for intraarticular pressure measurement in shoulder arthrograms which utilizes supplies readily available in any hospital or outpatient imaging center. Accurate measures of intraarticular pressure during a volume-limited arthrogram were safely performed. This preliminary report of technique and results represents a basis from which future pressure-limited procedures and studies could be generated.

Intraarticular pressure measurement has been previously described during arthrography of the glenohumeral joint.^{1–3} Bjorkenheim et al. found that by measuring the intraarticular pressure during the arthrogram and evaluating the resultant pressure-volume curve, they could increase their accuracy of diagnosing rotator cuff tears.¹ Resnik et al. utilized cadaveric and living patients' shoulders to evaluate the normal values of intraarticular pressure during injection of increasing volumes of fluid into the glenohumeral joint.³ Intraarticular pressure was monitored continuously during injection with a Harvard pump infusing at a rate of 4 mL/min. The infusion was stopped at 1–2 mL increments at which points the pressure was recorded after a 15-second equilibration period. As expected, subjects with adhesive capsulitis demonstrated higher pressures at lower volumes while those with rotator cuff tears had minimal increases in pressure compared to increasing volume. Hashimoto et al. utilized intraarticular pressure measurement to evaluate 83 patients with varying presentations of instability and rotator interval lesions versus a control group.² The data suggest that the pressure variation ranges in the two groups were not significantly

Fig. 4. Set-up and attachment of the three-way stopcock line, and transducer cable.

different than the control group.

In more recent studies, measurement of capsular area on MRAs has been shown to be beneficial in assisting in the diagnosis of posterior and multidirectional instability of the glenohumeral joint.^{4,5} Dewing et al. reported that linear and capsular area measurements on MRAs were increased in patients with posterior and multidirectional instability.⁴ Another recent study by Galvin et al. verified these findings and also used Receiver Operating Characteristic (ROC) curves to identify the sensitivity and specificity of cutoff values to help quantify a pathologic patulous capsule.⁵ However, both of these studies noted a major limitation of these capsular measurements with volume-limited arthrography techniques. As posterior shoulder instability is becoming more

commonly recognized, it is important to improve diagnostic techniques and a pressure-limited study could provide a uniform value by which to compare capsular area measurements.^{6–9}

This study secondarily sought to determine if there is variability in intraarticular pressure measurements based on patient morphology and injury during a volume-limited arthrogram, though, significant differences were not observed which is likely due to the small sample size. However, we did find a large range of intraarticular pressures from 15 to 181 mmHg in our study population using a standard volume for arthrograms. This is an important finding and given the different ranges of intraarticular pressure measurements with uniform volume, using a standardized intraarticular pressure to help dictate the amount of contrast to inject into the glenohumeral joint could be utilized to improve the accuracy of diagnosis in patients with posterior or multidirectional instability and patulous capsules. We believe this simple technique could be readily employed for future larger-scale studies.

Technical limitations of this study include the fact that pressure measurement occurred at a single point in time and does not reflect changes in pressure as the fluid infiltrates the joint, or changes in pressure that could occur from injection to actual MRA. In an attempt to control for the variable of fluid extension, all pressure measurements were made immediately after injection of 10 cc, and there was a clear equilibration pressure which remained constant for approximately 5 s. After 5 s, the pressure was noted to drop and we hypothesize that this is due to extension into the subscapular recess or bicipital sheath. However, utilization of a digital, real-time, pressure manometer could account for any changes as well as monitor pressure as a function of time and as a function of volume, only further improving reliability of the measurements. Another limitation is that we did not record time from injury to arthrogram as a data point in this study. As seen in patient #4, timing may have a profound effect on the pressure measurement and this should be considered in future studies. While there were no rotator cuff injuries included in this study, and no apparent capsular injuries based on the final imaging/surgical findings in each patient, these scenarios could present challenges in real-world application of pressure-limited techniques. Lastly, there are possibly other variables unaccounted for in the current study that could have an impact, to include: dysplasia or bone loss,¹⁰ glenoid version (Friedman's angle),¹¹ humeral head subluxation,¹² humeral head size, capsular area measurements, and ligamentous laxity.

5. Conclusion

We present a simple, cost-effective technique for pressure measurement following a volume-limited shoulder arthrogram. These

Fig. 5. After zeroing the monitor connected to the arterial line pressure transducer, 8 mL of the contrast mixture is injected into the glenohumeral joint and the pressure measurement is obtained.

Table 1
Patient data for volume-limited pressure measurement arthrograms.

#	Age	Sex	Laterality	Height (in)	Weight (lbs)	BMI* (kg/m ²)	Instability (direction)	Pressure (mmHg)	VAS [‡] -pre	VAS [‡] -post	Working Diagnosis	Surgery Performed
1	28	M	L	67	225	35.2	Anterior	15	2	0	Anterior instability	Bankart repair
2	24	M	R	76	245	29.8	Anterior	40	2	0	Anterior instability	Bankart repair
3	23	M	R	70	185	26.5	Anterior	41	2	2.5	Anterior instability	Bankart repair
4	27	M	R	68	200	30.4	Anterior	181	1	1	Anterior instability	None
5	31	M	L	74	230	29.5	Posterior	60	4	4	Posterior instability	None
6	36	M	L	70	190	27.3	None	31	0	0	Biceps tendinopathy	None
7	26	M	L	67	155	24.3	None	35	2	1	Biceps tendinopathy	Biceps tenodesis
8	23	F	R	60	118	23.0	MDI	117	7	7	MDI	None
9	28	M	R	69	170	25.1	None	31	6	0	AC joint arthritis	Open Mumford
10	29	M	R	72	258	35.0	None	64	3	0	AC joint Arthritis	None
11	26	M	R	69	169	25.0	None	58	4	3	AC joint arthritis	None
12	38	M	L	68	212	32.2	None	44	8	8	Biceps tendinopathy	None
13	36	M	R	69	187	27.6	None	30	2	N/A	Biceps tendinopathy	Biceps tenodesis
14	22	F	L	54	180	26.6	Anterior	92	N/A	N/A	Anterior instability	Bankart

* Body Mass Index.

‡ Visual Analogue Scale Score.

Table 2
Comparison of instability group versus control group.

	Instability Group	Control Group	P-value
# of Patients	7	7	1.0
Male: Female	5:2	7:0	> 0.4
Age (years)	25.4 ± 3.3 (range 22–31)	31.3 ± 5.2 (range 26–38)	< 0.03
Left: Right	3:4	3:4	1.0
BMI* (kg/m ²)	28.7 ± 3.8 (range 23.0–35.2)	28.1 ± 4.0 (range 24.3–35.0)	> 0.7
Pre- VAS [‡] Score	3.0 ± 2.2 (range 1–7)	3.6 ± 2.7 (range 0–8)	> 0.6
Post- VAS [‡] Score	2.4 ± 2.7 (range 0–7)	2.0 ± 3.2 (range 0–8)	> 0.8
Intraarticular Pressure (mmHg)	60.8 ± 37.6 (range 15–117)	41.9 ± 14.0 (range 30–64)	> 0.1

* Body Mass Index.

‡ Visual Analogue Scale Score.

Table 3
Multiple regression analysis of independent variables on pressure measurements.

Regression Statistics					
R Square					0.95
Adjusted R Square					0.80
Standard Error					12.54
Observations					13.00
ANOVA					
	df	SS	MS	F	Significance F
Regression	9.00	8925.24	991.69	6.31	0.08
Residual	3.00	471.84	157.28		
Total	12.00	9397.08			
	P-value	Lower 95%	Upper 95%		
Intercept (pressure)	0.17	−929.25	264.06		
Age	0.18	−6.50	1.92		
Height	0.21	−3.64	10.81		
Weight	0.75	−0.91	1.14		
BMI*	0.88	−8.37	9.30		
Pre-VAS [‡]	0.59	−10.59	7.23		
Post-VAS [‡]	0.16	−3.53	13.80		
Sex	0.04	10.50	206.40		
Laterality	0.81	−34.61	29.41		
Instability	0.13	−15.31	70.48		

*Body Mass Index, ‡Visual Analogue Scale Score.

preliminary data suggest that glenohumeral pressure measurements are variable depending on patient morphology and pathology utilizing a standardized volume-limited arthrogram technique.

Declarations of interest

None.

Summary statement

We present a simple, cost-effective technique for pressure measurement following a standard, volume-limited arthrogram from which the data suggest that glenohumeral pressure measurements are variable depending on patient morphology and pathology.

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