



● *Technical Note*

VALIDATION OF ULTRASOUND MEASUREMENT OF THE SUBACROMIAL SPACE USING A NOVEL SHOULDER PHANTOM MODEL

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Abstract—Ultrasound has a high degree of diagnostic accuracy in the assessment of rotator cuff tendons. Increasingly, ultrasound is being used to measure other parameters of rotator cuff pathology, including the size of the subacromial space, or acromiohumeral distance (AHD). Although this measure has been found to be clinically reliable, no assessment of its validity has been carried out. This technical study reports on the development of a novel ultrasound phantom of the shoulder and its use in validation of ultrasound measurement of AHD. There was a close agreement between AHD measures using ultrasound and the true subacromial space of the phantom model, providing support for the construct validity of this measurement. The phantom model has good potential for further development as a training tool for shoulder ultrasound and guided injections. (E-mail: karen.mccreesh@ul.ie) © 2014 World Federation for Ultrasound in Medicine & Biology.

Key Words: Ultrasound phantom, Shoulder, Acromiohumeral distance.

INTRODUCTION

The self-reported prevalence of shoulder pain in adults averages between 15% and 20% in European population studies (Pribicevic 2012), with the most common diagnosis being disorders of the rotator cuff tendons. Ultrasound has been found to be comparable in its diagnostic accuracy to magnetic resonance imaging (MRI) for identifying rotator cuff tears (De Jesus et al. 2009). Ultrasound findings in rotator cuff disorders include bursal thickening, tendon hypo-echogenicity and partial- or full-thickness tendon tears. Rotator cuff (RC) tendinopathy can lead to superior migration of the humerus as a result of failure of RC stabilization, and the resultant narrowing of the subacromial space may cause further tendon impingement (Lewis 2010). A reduction in the subacromial space has been reported in people with painful RC pathology (Saupe et al. 2006), and many interventions for RC pathology, for example, acromioplasty

surgery and exercise programs, are founded on an attempt to increase the subacromial space and, thus, relieve symptoms.

Radiographic examination has traditionally been used to assess for narrowing of the subacromial space in people with rotator cuff pathology, through measurement of the acromiohumeral distance (AHD). However, a recent systematic review found ultrasound to be the best method of AHD measurement because of the good evidence for its reliability, in contrast to the limited evidence for the reliability of radiographic methods (McCreesh et al. 2013). Reliability is an important property of a measurement, demonstrating consistency between measures and examiners; however, the validity of a measurement is also important to confirm the accuracy of the method. Although studies have been completed comparing different radiologic methods of AHD measurement in an attempt to provide some evidence for concurrent validity (Azzoni et al. 2004; Saupe et al. 2006; Werner et al. 2008), there remains no accepted “gold standard” for this measurement and no studies examining its construct validity. In a study aimed at assessing the amount of bone removal during arthroscopic subacromial

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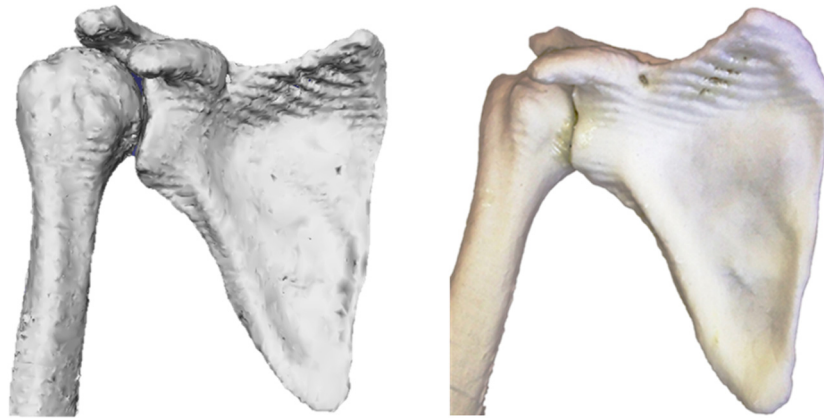


Fig. 1. Computerized 3-D shoulder model (*left*) and the printed out bones (*right*).

decompression surgery, [Tillander and Norlin \(2002\)](#) intra-operatively measured AHD in people with and without subacromial pathology. Although it was found that those with subacromial pathology had significantly smaller AHDs, there was no comparison made to AHD measurement by any non-invasive method. Although the intra-operative method provides a potential *in vivo* method of assessing the construct validity of AHD measurement, numerous variables associated with the peri-operative condition, for example, patient position, arm traction and introduction of fluid, prevent it from being an appropriate model for investigation. Validity of ultrasound imaging methods and measurements is commonly assessed by the use of an appropriate tissue-mimicking phantom ([Koski et al. 2010](#); [Thijssen et al. 2007](#)). As no study to date has examined the construct validity of AHD measurement, the aim of this study was to evaluate the construct validity of ultrasound measurement of AHD using a newly developed shoulder ultrasound phantom.

METHODS

Development of the phantom

A novel ultrasound phantom of the shoulder was developed. A DICOM computed tomography (CT) data set of a shoulder was used to create a computerized 3-D model of the superior half of the humerus and scapula. A 3-D rapid prototyping printer (Vanguard HS HiQ SLS: 3-D systems, Rockhill, Moffat, UK) was used to print a bone phantom for each bone (humerus and scapula) out of DuraForm PA (3-D Systems, Valencia, CA, USA) (see [Fig. 1](#)). The bones were placed in the correct alignment (with reference to the DICOM images), and rubber washers with epoxy resin were used to create the appropriate spacing. A custom mold was made of an appropriately sized shoulder, into which a compound containing gelatin, psyllium husk powder and chlorhexidine was poured. The bones were then embedded in this compound.

Once the compound had set, the model was covered in latex paint to improve durability and resilience (see [Fig. 2](#)). Our investigation of a sample of the two materials indicated that the DuraForm PA had a speed of sound of 1709 ms^{-1} , whereas the gelatin compound had a speed of sound of 1550 ms^{-1} , closely matched to the average speed of sound in soft tissue (1540 ms^{-1}). Acromiohumeral distance, measured as the shortest distance between the inferolateral acromion and the adjacent part of the humeral head, was measured directly with Vernier callipers on the completed shoulder “joint” before it was embedded in gelatin. Five measures were taken.

Measurement validation

Measurement of AHD on the shoulder phantom was independently undertaken by two musculoskeletal sonographers blind to the true reference value of AHD in the phantom. Ultrasound examination was undertaken with a GE Logiq e ultrasound scanner (GE Medical, Wauwatosa, WI, USA) with a 7- to 12-MHz linear array



Fig. 2. Completed shoulder phantom model.

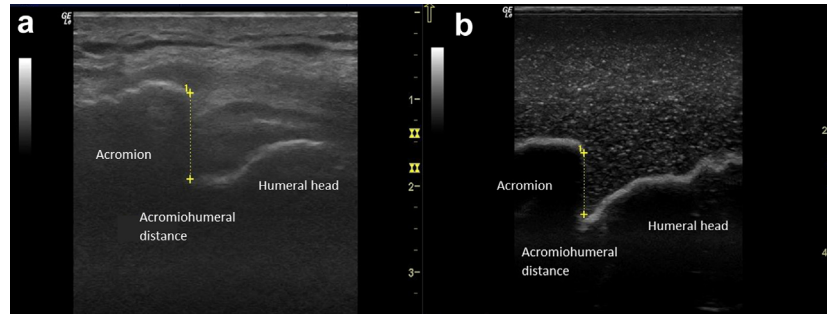


Fig. 3. (a) Ultrasound image of acromiohumeral distance in a normal shoulder. (b) Corresponding image of shoulder phantom.

transducer. An ultrasound image was obtained with the transducer positioned along the line of the humerus, over the anterior part of the acromion, with the subacromial space and humeral head visible. The AHD was then measured as the shortest distance between the inferolateral edge of the anterior acromion and the humeral head, parallel to the acoustic shadow cast by the acromion (see Fig. 3 for an image of AHD measurement from a normal shoulder alongside an image from the shoulder phantom). AHD was measured using on-screen callipers. Each examiner independently measured the AHD on five separate images, with the probe removed and repositioned between scans.

Data analysis

Descriptive values were calculated of the mean, standard deviation and coefficient of variation for the calliper and ultrasound measures (twice by examiner 1 and once by examiner 2). The values from examiner 1 were used for the intermethod comparison. A boxplot was constructed to examine the spread of data points. A Bland-Altman plot was constructed for the intermethod comparison between AHD measurements made directly using callipers and those made with ultrasound. As per the suggestion of Krouwer (2008), the difference between the methods were plotted against the calliper measurements (rather than against the mean of the two measures), as it was deemed the reference method. The Wilcoxon signed rank test was used to examine whether there were any differences between AHD measures made with callipers and those acquired using ultrasound, as well as between testers.

RESULTS

Table 1 lists the descriptive values of the AHD measurements made with callipers directly on the bony “joint” before embedding, as well as the ultrasound measures made by both examiners. All methods had excellent reliability, with coefficients of variation below 3%. There

were no statistically significant differences between AHD measures made with callipers and those made with ultrasound ($p = 0.27$), or between intrarater ($p = 0.83$) and interrater ($p = 0.09$) ultrasound measurements. The boxplot in Figure 4 illustrates good agreement across all measurements, all with medians within 0.5 mm of each other and all measures falling within 1 mm. The Bland-Altman plot in Figure 5 illustrates very good agreement, with a mean difference of only 0.14 mm and limits of agreement between -0.44 and 0.72 mm.

DISCUSSION

This study investigated the construct validity of ultrasound measurement of AHD using a shoulder phantom. The Duraform PA and gelatin-based phantom proved to be a very suitable model, similar in look, shape and feel to a real shoulder joint, providing lifelike ultrasound images. Ultrasound-measured AHD values were very close to the true “skeletal” measurement with callipers, confirming the construct validity of the ultrasound measures. The reliability of the ultrasound AHD measures was also excellent.

Acromiohumeral distance in normal healthy shoulders ranges between 7 and 12 mm (McCreesh *et al.*

Table 1. Descriptive values for acromiohumeral distance measurements of the shoulder phantom made directly with callipers and indirectly using ultrasound by two sonographers*

	Measurement with callipers	Ultrasound measurement		
		Tester 1		Tester 2
		Time 1	Time 2	
Mean (mm)	9.9	9.7	9.7	9.4
Standard deviation (mm)	0.2	0.2	0.1	0.2
Coefficient of variation (%)	3	1.9	0.9	2
Significance of difference	$p = 0.27$	$p = 0.83$		$p = 0.09$

* Values taken from five repeated measurements in each case.

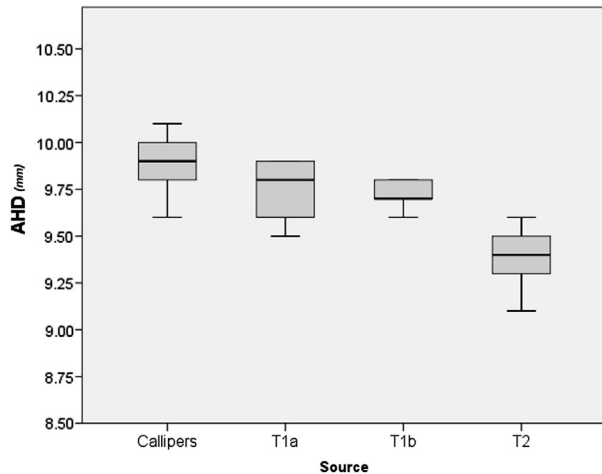


Fig. 4. Boxplot illustrating acromiohumeral distance (AHD) measurements made with callipers and using ultrasound. T1 = tester 1, T2 = tester 2.

2013). A reduction in AHD has been found to be present in people with rotator cuff pathology, with reductions below 6 mm thought to be indicative of a significant rotator cuff tear (Goutallier et al. 2011). Saupé et al. (2006) reported that AHD was associated with the degree of fatty degeneration of the rotator cuff muscles, which is an important predictor of surgical outcomes for rotator cuff repair. In a pilot study of people with shoulder pain undergoing physiotherapy, Desmeules et al. (2004) found that there was a strong positive correlation between an increase in the AHD and functional improvement after rehabilitation. It is clear that further studies in symptomatic populations are required to ascertain the full clinical value of AHD measurement, but it may prove a useful diagnostic indicator in rotator cuff pathology.

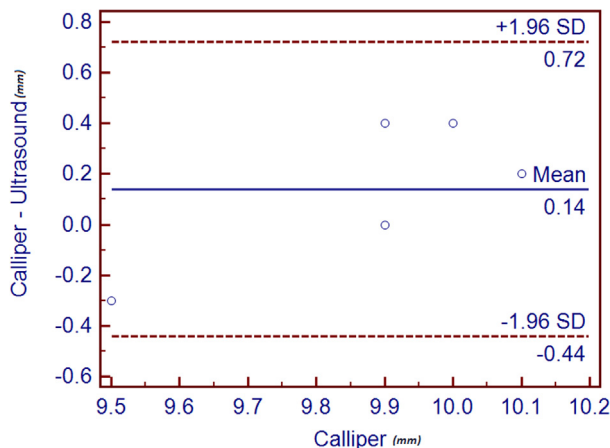


Fig. 5. Bland–Altman plot comparing the acromiohumeral distance (AHD) measurements made with callipers and by ultrasound (tester 1 measures). The mean difference was 0.14 mm, and the limits of agreement were -0.44 mm and 0.72 mm.

Ultrasound has been found to be a highly reliable method of AHD measurement in both healthy and shoulder pain populations, with CT and MRI providing reasonable evidence of their reliability, but little evidence to support the reliability of radiographic methods (McCreesh et al. 2013). Each radiologic method of AHD measurement has potential shortcomings. With radiographs, projection issues and bony overlap may lead to difficulty defining the area of measurement. During ultrasound examination, the acromion produces an acoustic shadow that may obscure the area of AHD measurement. The upright positioning for ultrasound and radiographs is consistent with the functional position for the shoulder; however, for MRI and CT imaging, the patient assumes the supine position, leading to a potentially smaller AHD measurement because of the lack of the effect of arm weight. A comparison of AHD measurement between MR images and radiographs was carried out by Saupé et al. (2006), who reported poor correlation between the methods and consistently lower values for the MR image.

Despite the widespread use of diagnostic ultrasound imaging of the shoulder, there is no published work in the area of ultrasound phantoms of the shoulder. As a pilot phantom, this model had some limitations in terms of AHD measurement, namely, the lack of soft tissue-mimicking components and also the fact that the model was set in the “supine” position, rather than the more usual upright position used for shoulder ultrasound. Although we ensured good fixation of the bones and undertook minimal movement of the phantom, we cannot guarantee that the subacromial space did not alter after embedment in the phantom. We did not undertake an assessment of the attenuation properties of the completed phantom, as we were not intent on creating a phantom with perfect tissue-matching properties. Gelatin-water mixtures, with the use of husk material to create a speckle pattern, are well accepted as appropriate for the simulation of soft tissues. A full quantitative assessment of these mixtures by Madsen et al. (2005) indicates that the attenuation of our material should lie between 0.3 and 0.5 dB/cm/MHz and, thus, be an acceptable soft tissue mimic. The ultrasound image of the phantom shares many characteristics of a true shoulder appearance, with the grainy appearance of the soft tissues and the reflective appearance of the bone model, with the appropriate degree of acoustic shadowing. With further development, the phantom has excellent potential as a model for training in diagnostic shoulder ultrasound, as it provided images that share similarities with clinical musculoskeletal images of the shoulder. It also has potential as a tool for practicing ultrasound guided shoulder injections. Further development would require addition of realistic tendon phantoms of the rotator cuff and biceps tendons, as well as the use

of self-healing materials, to optimize its usefulness for injection training.

CONCLUSIONS

This study provides evidence of the construct validity of AHD measurement with ultrasound, using a novel ultrasound phantom. Further research is required to better understand the relative importance of AHD in shoulder pathology and how it is affected by rehabilitation and surgery. The shoulder phantom has potential for further development as a training tool for ultrasound shoulder examination and ultrasound-guided shoulder injections.

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