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## Assessment of Glenohumeral Subluxation in Poststroke Hemiplegia: Comparison Between Ultrasound and Fingerbreadth Palpation Methods

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## Assessment of Glenohumeral Subluxation in Poststroke Hemiplegia: Comparison Between Ultrasound and Fingerbreadth Palpation Methods

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**Background.** Glenohumeral subluxation (GHS) is a common poststroke complication. Treatment of GHS is hampered by the lack of objective, real-time clinical measurements.

**Objective.** The aims of this study were: (1) to compare an ultrasound method of GHS measurement with the fingerbreadth palpation method using a receiver operating characteristic curve (ROC) and (2) to report the sensitivity and specificity of this method.

**Design.** A prospective study was conducted.

**Setting.** The study was conducted in local hospitals and day centers in the southwest of England.

**Patients.** One hundred five patients who had one-sided weakness following a first-time stroke (51 men, 54 women; mean age=71 years, SD=11) and who gave informed consent were enrolled in the study.

**Measurements.** Ultrasound measurements of acromion-greater tuberosity (AGT) distance were used for the assessment of GHS. Measurements were undertaken on both shoulders by a research physical therapist trained in shoulder ultrasound with the patient seated in a standardized position. Fingerbreadth palpation assessment of GHS was undertaken by a clinical physical therapist based at the hospital, who also visited the day centers.

**Results.** The area under the ROC curve was 0.73 (95% confidence interval [95% CI]=0.63, 0.83), suggesting that the ultrasound method has good agreement compared with the fingerbreadth palpation method. A cutoff point of  $\geq 0.2$  cm AGT measurement difference between affected and unaffected shoulders generated a sensitivity of 68% (95% CI=51%, 75%), a specificity of 62% (95% CI=47%, 80%), a positive likelihood ratio of 1.79 (95% CI=1.1, 2.9), and a negative likelihood ratio of 0.55 (95% CI=0.4, 0.8).

**Limitations.** Clinical therapists involved in the routine care of patients conducted the fingerbreadth palpation method. It is likely that they were aware of the patients' subluxation status.

**Conclusion.** The ultrasound method can detect minor asymmetry ( $\leq 0.5$  cm) and has the potential advantage over the fingerbreadth palpation method of identifying patients with minor subluxation.



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**G**lenohumeral subluxation (GHS) is a recognized complication in people with poststroke hemiplegia. The reported incidence of GHS ranges from 17% to 81% of patients, depending on the measurement methods used and the time frames over which it is assessed.<sup>1,2</sup> Severe loss of motor function and apparent absence of supraspinatus muscle contraction are potential risk factors for GHS, but scapular orientation does not contribute to GHS, as was originally thought.<sup>3</sup> The association between GHS and other poststroke complications such as pain and poor motor recovery is uncertain. When present in combination, however, these complications could have a significant impact on upper limb function.<sup>4</sup> The management of GHS, therefore, is an important therapeutic goal, and various approaches have been used in its prevention and treatment.<sup>5,6</sup> Current approaches have significant problems and limitations to their use, and the effectiveness of any one of these approaches for the treatment of GHS is inconclusive.<sup>7</sup> A potential reason for these findings is the lack of reliable, objective, real-time clinical measurements.<sup>8</sup> Current clinical measurements include the fingerbreadth palpation method<sup>9</sup> and plain radiographs.<sup>6,10</sup>

The fingerbreadth palpation method lacks the sensitivity to detect early signs of GHS or minor subluxations.<sup>8</sup> There is a concern that without treatment, subluxation can progress to an uncorrectable level over time.<sup>6</sup> Early GHS can contribute to irreversible partial or complete tears of the non-elastic shoulder capsule.<sup>5,6,11</sup> Radiographs are considered to be objective and have high reliability and validity,<sup>12</sup> but problems relating to cost, time involved, and risks inherent to exposure to radiation<sup>13</sup> limit their utility in the clinical setting. In addition, radiographic diagnosis is

not generally recommended for clinical evaluation of GHS.<sup>14</sup>

Diagnostic ultrasound is now routinely used for clinical imaging of the shoulder region in patients with musculoskeletal conditions.<sup>15-18</sup> Recently, several studies used diagnostic ultrasound to evaluate the incidence and prevalence of soft tissue injuries (rotator cuff tears, biceps tendinitis) in the shoulders of people with poststroke hemiplegia.<sup>19-26</sup> The ultrasound method is currently being investigated and developed for the assessment of GHS in these patients<sup>27,28</sup>; however, it is not routinely used in clinical settings. Using a large, static ultrasound machine, Park et al<sup>27</sup> reported high intrarater reliability (intraclass correlation coefficient [ICC]=.979) of ultrasound measurements of GHS. More recently, Kumar et al<sup>28</sup> recruited 26 patients with stroke and, using a new standardized position with the forearm supported, found that bedside assessment of acromion-greater tuberosity (AGT) distance, undertaken by a physical therapist trained in shoulder ultrasound, demonstrated good intrarater reliability (ICC=.980) and discriminant validity.

The purposes of this study were: (1) to compare ultrasound and fingerbreadth palpation methods of GHS measurements using a receiver operating characteristic (ROC) curve and (2) to report the sensitivity and specificity of these methods. The fingerbreadth palpation method is routinely used in clinical practice and has been tested for both reliability and validity.<sup>29-31</sup> Hall et al<sup>29</sup> investigated the concurrent validity of this method by comparing it with plain radiographs. They reported a Spearman correlation coefficient of .760 between the fingerbreadth palpation method and plain radiographs. This study continued this research by


comparing ultrasound and fingerbreadth palpation methods.

## Method

### Participants

The study used a prospective design and received approval from the National Health Service (NHS) Research Ethics Committee, North Bristol Trust, United Kingdom. Patients over 50 years of age who had stroke resulting in one-sided weakness and who were able to sit upright were eligible to participate. Patients with aphasia also were eligible to participate in the study. Aphasia was confirmed if a patient had difficulty following simple commands, understanding questions (receptive aphasia), or speaking (expressive aphasia). Diagnosis or presence of GHS was not a requirement to be able to participate in the study. Patients with other neurologic conditions, traumatic brain injury, brain tumors or other serious comorbidities, shoulder pathology, or recent surgery to the neck, arm, or shoulder; those who were unavailable for testing; and those who were unable to volunteer due to any reason were excluded.

An a priori power calculation was performed for assessing the clinical utility of the ultrasound method as quantified by the area under the receiver operating characteristic (AUROC) curve. To our knowledge, this is the first study of this topic using AUROC curve statistics. Therefore, power calculations were conducted for 2 AUROC curve values. For standard level of significance

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- [eTable](#): AUROC Curve Statistics With 95% CI for Ultrasound Method Using Optimal Cutoff Point

## Comparison of Ultrasound and Fingerbreadth Palpation Methods

**A** Fingerbreadth Palpation Method



**B** Ultrasound Method



**Figure 1.**

Participants' standardized position for data collection: (A) fingerbreadth palpation method, (B) ultrasound method.

( $\alpha = .05$ ,  $\beta \leq .20$ ), a minimum sample size of  $n = 72$  and  $n = 114$  would have at least 80% power to determine statistical significance if the true AUROC was equal to 0.70 and 0.65, respectively, assuming a 1:1 ratio between negative and positive cases in the sample (calculations were performed using MedCalc Software, version 11.1, Mariakerke, Belgium). Therefore, the aim of this study was to recruit up to 114 patients with stroke.

Patients were recruited from 4 local hospital trusts in the southwest of England and from the community by accessing the Bristol Area Stroke Foundation (BASF), a voluntary organization that operates social clubs in a number of day centers for patients with stroke in Bristol. Of the several BASF social clubs, 6 centers located in and around the Bristol area were approached for the recruitment of patients. Each patient gave informed written consent to take part, and, for those who lacked mental capacity, appropriate procedures were followed and involved a family member signing the personal consultee agreement form in the presence of the patient.

### Apparatus and Raters

Prior to commencement of the data collection process, a portable diagnostic ultrasound machine (TITAN model, L38/10-5 MHz broadband, Sonosite Ltd, Hitchin, United Kingdom) was tested and calibrated according to the manufacturer's guidelines.

Ultrasound measurements of AGT distance were undertaken by a physical therapist (P.K.) at all of the research sites (hospital and day centers). The training protocol consisted of a 1-day manufacturer's course, supervised training from a consultant radiologist, pilot work on 6 healthy volunteers, and reliability studies on healthy volunteers<sup>32</sup> and patients with stroke ( $n = 64$ ).<sup>28</sup>

Clinical assessment of GHS (using the fingerbreadth palpation method) was performed by one of the senior clinical physical therapists (NHS bands 6-8) at each local hospital trust and at the day centers. Seven physical therapists with 4 to 15 years of experience in stroke rehabilitation were involved with clinical assessments of GHS. To ensure standardization and familiarization with the testing procedure, each physical

therapist practiced the standardized protocol on 2 patients with stroke in the presence of the chief researcher (P.K.). Any issues arising were discussed and clarified at this stage. During actual data collection, physical therapists undertook measurements independently.

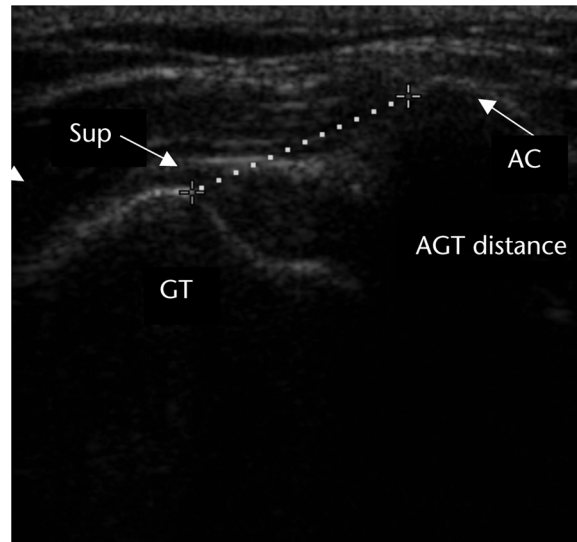
### Procedure

Baseline demographic data, including age, sex, date of onset, type of stroke, site of stroke, and side affected, were collected from patients' medical records by the chief researcher. For patients at day centers, only age, sex, and date of stroke were gathered directly from the patients, as no medical records were available. Assessments were conducted at the hospital bedside or in the day centers. The therapist undertaking clinical assessment of GHS was blinded to ultrasound measurements of AGT distance, and the therapist undertaking ultrasound measurements was blinded to clinical assessment. The order of data collection was as follows.

**Clinical assessment of GHS by a clinical physical therapist using the fingerbreadth palpation method.** A standardized protocol was used.<sup>29</sup> Patients were seated in a chair or wheelchair with both feet flat on the ground or on a footrest. The physical therapist first assessed the unaffected side to palpate the gap between the acromion and the head of the humerus, and this assessment was repeated on the affected shoulder. Shoulders were positioned in neutral rotation, with the arm hanging by the side (thumb pointing forward) close to the body with no abduction (Fig. 1). Some patients who demonstrated high tone were unable to hang their affected arm freely by the side. For these patients, the shoulder was maintained in internal rotation with slight elbow flexion and the forearm resting on their lap. Glenohumeral subluxation was

defined as a palpable gap between the inferior aspect of the acromion and the superior aspect of the humeral head that is  $\frac{1}{2}$  fingerbreadth or more. A 0-5 grading scheme was used: 0=no subluxation, 1= $\frac{1}{2}$  fingerbreadth gap, 2=1 fingerbreadth gap, 3= $1\frac{1}{2}$  fingerbreadth gap, 4=2 fingerbreadth gap, and 5= $2\frac{1}{2}$  fingerbreadth gap.<sup>29</sup>

**Ultrasound measurements of AGT distance by the chief researcher.** For ultrasound measurements of AGT distance, each patient was placed in the standardized position to allow measurement of AGT distance (Fig. 1).<sup>32</sup> The shoulder was in neutral rotation, with the elbow at 90 degrees of flexion and the forearm in pronation. The forearms rested on a pillow placed on the patient's lap with the elbow joint itself remaining unsupported. Assistance was provided by the researcher if the patient was unable to move the arm. The ultrasound transducer then was placed over the lateral border of acromion along the vertical/longitudinal axis of the humerus to scan the shoulder. The AGT distance was recorded on the frozen image using an on-screen caliper that automatically calculates distances (Fig. 2). The AGT distance was defined as the relative lateral distance between the lateral edge of the acromial process of the scapula and the nearest margin of the superior part of the greater tuberosity of the humerus.<sup>32</sup> A dark linear acoustic shadow beneath the acromion helped to identify the lateral edge of the acromion. The supraspinatus tendon was clearly visible as a thick band (acoustic hyperechoic appearance) at its point of insertion, which facilitated identification of the greater tuberosity (Fig 2). Three ultrasound images of the right shoulder were obtained, and AGT distance was measured on each image. This process was repeated on the left shoulder. In order to ensure the rater



**Figure 2.**

Measurement of acromion-greater tuberosity (AGT) distance between the lateral border of the acromion (AC) and the nearest superior margin of the greater tuberosity (GT). Dotted caliper represents AGT distance. Sup=supraspinatus muscle.

was blind to measurements, the values displayed were obscured by placing a sticker on the ultrasound screen.

**A general neurological clinical examination of the upper limb by the chief researcher.** The general neurological examination included assessment of muscle strength in the shoulder muscles (Medical Research Council Scale)<sup>33</sup> and muscle tone<sup>34,35</sup> on both affected and unaffected sides. Muscle tone was classified as low (grade 0), normal (grade 1), and high (grades 2-5), as described by Culham et al.<sup>35</sup> For both muscle strength and tone, the shoulder flexors, abductors, and internal and external rotators were assessed.

**Data Analysis**

Data were analyzed using SPSS (version 19.0, IBM UK, Business Analytics, Middlesex, United Kingdom). Descriptive statistics were used to calculate the mean and standard deviation of AGT distance measurements for both affected and unaffected shoulders. The difference between affected and unaffected

shoulders was considered a measure of GHS based on the ultrasound method and was analyzed using repeated-measures analysis of variance (ANOVA), and both sides (affected and unaffected) and time were considered as within-subject factors. The standard error of measurement (SEM) was calculated from the ANOVA output. The minimum detectable change with 90% confidence interval (MDC<sub>90</sub>) was calculated using the formula:  $MDC_{90} = SEM \times 1.65 \times \sqrt{2}$ .<sup>36,37</sup>

The association between the fingerbreadth palpation method (difference between affected and unaffected shoulders) and the ultrasound method was tested using Spearman rank correlation coefficients. This statistical test is used when one of the methods (in this case, the fingerbreadth palpation method) generates ordinal data rather than interval or ratio data. Agreement between the ultrasound and fingerbreadth palpation methods was tested using the ROC curve, the AUROC curve, sensitivity, specificity, negative and positive predictive values, and likeli-

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**Table 1.**  
Demographic Characteristics of Patients With Stroke (n=105)

Variable	Measurements
Age (y)	
$\bar{x}$	71
SD	11
Range	50–90
Sex, n (%)	
Male	51 (48)
Female	54 (52)
Type of stroke, n (%)	
Cerebral infarction	66 (62)
Intracerebral hemorrhage	10 (9)
Unspecified	29 (29)
Side affected, n (%)	
Right	51 (48)
Left	54 (52)
Aphasia, n (%)	22 (21)
Muscle strength <sup>42</sup> (shoulder flexors, abductors, rotators), n (%)	
≤3	79 (75)
≥4	26 (25)
Muscle tone <sup>44</sup> (shoulder flexors, abductors, rotators), n (%)	
Low	42 (40)
Normal	40 (38)
High	23 (22)
Time since onset of stroke (wk)	
Median	5.6
Range	0.4–728

hood ratios for different values of ultrasound measurements of AGT distance.

### Role of the Funding Source

This research was undertaken as part of Dr Kumar's doctoral thesis, which was funded by the University of the West of England, Bristol, United Kingdom.

### Results

Over a 16-month period, 115 patients with stroke were approached to participate in the study. Ten patients were excluded because they did not meet the inclusion criteria. Of these patients, 3 had serious comorbidities (intestinal cancer, heart problems), 1 was enrolled

but withdrew before finishing data collection, 1 was discharged from the hospital prior to data collection, and 5 could not visit the day center on the day of data collection because of personal reasons. Therefore, 105 patients agreed to participate and were enrolled in the study: 70 patients were from hospital settings, and 35 patients were from stroke day centers. Of the recruited patients, 22 (21%) had aphasia. Seven patients required alternative positioning (a nonstandard modified sitting position) due to the presence of high tone.

A summary of the demographic characteristics of the participants is shown in Table 1. The mean AGT

distance for the total sample (n=105) was 2.2 cm (SD=0.6) and 1.8 cm (SD=0.4) for the stroke-affected and stroke-unaffected shoulders, respectively. On the stroke-affected side, the minimum and maximum AGT values recorded across patients were 1.0 and 3.7 cm, respectively, and the 95% confidence intervals (95% CIs) ranged from 2.0 to 2.3 cm. Corresponding values for the unaffected shoulder were 0.7, 3.2, and 1.7 to 1.9 cm. The repeated-measures ANOVA showed a significant mean AGT difference between affected and unaffected shoulder measurements ( $\bar{x}$ =0.4 cm, SD=0.5) ( $F_{5,520}=53.101$ ,  $P<.001$ ). The SEM for the between-shoulder difference in AGT was 0.08 cm, and the MDC<sub>90</sub> was  $\pm 0.2$  cm.

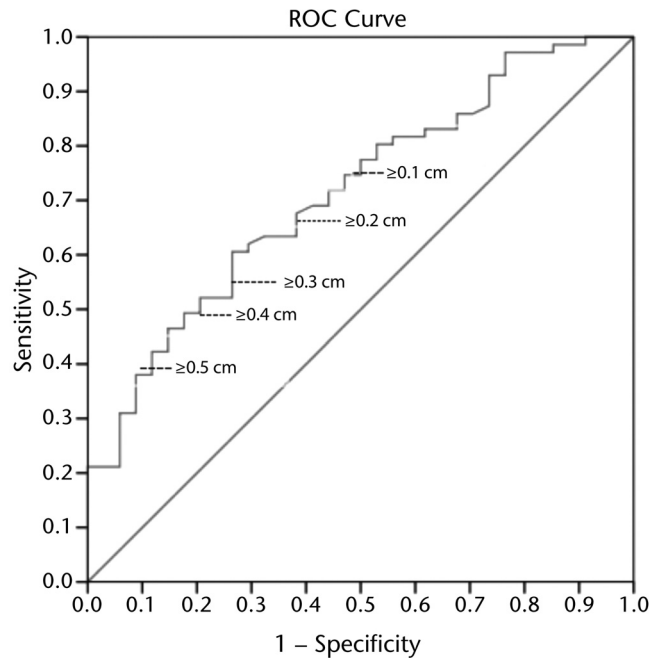
Shoulder subluxation was present in 71 patients (67%) and absent in 34 patients (33%) using the fingerbreadth palpation method of assessment. Of those with GHS, 31/71 (44%) had grade 1 (½-finger gap), 28/71 (39%) had grade 2 (1-finger gap), 8/71 (11%) had grade 3 (1½-finger gap), and 4/71 (6%) had grade 4 (2-finger gap) subluxation.

The Spearman rank correlation coefficients showed a moderate correlation ( $r_s=.52$ ) between the 2 methods, and this correlation was statistically significant ( $P<.001$ ). The ROC curve allows seeing, in a simple visual display, how sensitivity and specificity vary around different cut-off points (curved line) (Fig. 3). The AUROC curve can have any value between 0 and 1, and a test could be regarded as excellent or not useful based on the following categories: 0.9–1.0 (excellent), 0.8–0.9 (very good), 0.7–0.8 (good), 0.6–0.7 (sufficient), 0.5–0.6 (bad), and <0.5 (test has no diagnostic value).<sup>38,39</sup> If the AUROC curve value is 0.9 to 1.0 (ie, closer to the upper left-hand corner of the ROC curve), it demonstrates excellent agreement between

the tests. In contrast, if the value is  $\leq 0.5$  (ie, on or below the straight line), it suggests that there is poor agreement between the tests<sup>39</sup> (Fig. 3). The AUROC curve was 0.73 (95% CI=0.63, 0.83). Based on the AUROC curve, there was a good level of agreement between the ultrasound and fingerbreadth palpation methods.

Conventionally, on an ROC graph, a pair of diagnostic sensitivity and specificity values for every individual cutoff is plotted, with the sensitivity on the y-axis and 1 minus specificity on the x-axis. The sensitivity and specificity for various cutoff points are presented in Table 2. A cutoff point of  $\geq 0.2$  cm AGT measurement difference between affected and unaffected shoulders could be considered optimal because it provides the best trade-off between sensitivity and specificity, with a sensitivity of 68% (95% CI=51%, 75%) and a specificity of 62% (95% CI=47%, 80%). Using this cutoff point, the true value for the sensitivity of the ultrasound method is likely to be between 0.51 (the lower boundary of the CI), 0.68 (the point estimate), and 0.75 (the upper boundary of the CI).

Using the optimal cutoff point of  $\geq 0.2$  cm, the usefulness of the ultrasound method is illustrated in the eTable (available at ptjournal.apta.org). Likelihood ratios summarize how many times more or less likely patients with subluxation are to have a particular test result than patients without subluxation. The positive likelihood ratio of 1.79 suggests that a patient with subluxation (defined as grade of 1 or higher in the 5-point fingerbreadth palpation method) is 1.79 more likely to have an AGT difference greater than 0.2 cm on ultrasound than a patient without palpable subluxation. The flow diagram presented in Figure 4 illustrates the comparison of ultrasound method versus fingerbreadth



**Figure 3.**

Receiver operating characteristic (ROC) curve with area under the receiver operating characteristic (AUROC) curve value of 0.73 (95% confidence interval=0.63–0.83). Curved line shows sensitivity and specificity varied around different cutoff points. Straight line indicates AUROC curve  $\leq 0.5$  (test not useful). Cutoff points  $\geq 0.1$  to  $\geq 0.5$  cm correspond to sensitivity and specificity. Optimal cutoff point of  $\geq 0.2$  cm indicates 68% sensitivity and 62% specificity. Diagonal segments produced by ties.

palpation method. Using the ultrasound method, 61/105 patients (58%) had a mean AGT difference of  $\geq 0.2$  cm between the affected and unaffected shoulders. Of those patients with  $\geq 0.2$  cm AGT distance, 33/61 (54%) demonstrated a mean AGT difference of between 0.2 and 0.5 cm, indicating minor asymmetry between the unaffected and affected shoulders.

**Discussion**

The primary aims of this study were: (1) to compare an ultrasound method of GHS measurement with the fingerbreadth palpation method using an ROC curve and (2) to report the sensitivity and specificity of these methods. The AUROC curve from this study was 0.73. Presented with pairs of randomly selected patients, one with GHS and one

**Table 2.**

Sensitivity and Specificity With 95% CI for Ultrasound Method (AGT Distance Measurement Difference Between Affected and Unaffected Shoulders)<sup>a</sup>

Cutoff Point	Sensitivity	95% CI	Specificity	95% CI
$\geq 0.5$	40%	28%, 52%	89%	73%, 96%
$\geq 0.4$	47%	33%, 57%	83%	69%, 95%
$\geq 0.3$	55%	39%, 63%	74%	62%, 91%
$\geq 0.2$	68%	51%, 75%	62%	47%, 80%
$\geq 0.1$	76%	57%, 80%	50%	38%, 73%

<sup>a</sup> 95% CI=95% confidence interval, AGT=acromion–greater tuberosity.

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without GHS as determined by the fingerbreadth palpation method, an examiner would classify 73% of the pairs correctly by choosing the one whose AGT distance on ultrasound was the larger of the two.

For the diagnostic ultrasound method to be useful, it is important to select a trade-off between sensitivity and specificity.<sup>40</sup> The cutoff point of  $\geq 0.5$  cm generated a sensitivity of 40% (eTable). Examiners who apply a cutoff point of 0.5 cm while using the ultrasound method would fail to identify 6/10 patients judged by the fingerbreadth palpation method to have GHS. In contrast, a cutoff point of  $\geq 0.1$  cm generates a sensitivity of 76%, indicating that the ultrasound method would identify 8/10 patients with subluxation. However, this value is associated with a low specificity of 50%, indicating that 5/10 patients whose ultrasound measures are asymmetrical by  $\geq 0.1$  cm or more would have no evidence of GHS on the fingerbreadth palpation test. Unlike these cutoff points, which generate high sensitivity and low specificity or vice versa, a cutoff point of  $\geq 0.2$  cm generates a sensitivity of 68% and a specificity of 62%. Based on the sensitivity statistic, when the fingerbreadth palpation test indicates GHS, in 68% of those cases, the ultrasound measure also would indicate GHS.

The cutoff point of  $\geq 0.2$  cm (where the sensitivity is 0.68) may be considered optimal because it helps to “rule out” GHS by indicating that, among patients with subluxation (defined as a grade of 1 or higher on the 5-point palpation scale), 68% will have an AGT difference of at least 0.2 cm. This finding suggests that ultrasound potentially could be used as a screening tool, which is critical because early diagnosis of GHS would facilitate the application of appropriate treatment and thereby potentially prevent the long-term

complications associated with GHS. Furthermore, a cutoff point of  $\geq 0.2$  cm (where the test’s specificity is 0.62) indicates that, with a predicted false-positive result of 0.38, among those who demonstrate no subluxation (a grade of 0 on the 5-point fingerbreadth palpation scale), 62% will have an AGT difference of less than 0.2 cm. Specificity is equally important because applying treatment such as positioning (arm troughs, lap boards), shoulder slings, or strapping to a patient without GHS could reduce the normal gap between the acromion and the head of the humerus. This position could alter the normal scapulohumeral rhythm required for smooth movement at the shoulder joint resulting in compression of the rotator cuff tendons under the acromion process, which can cause tearing of these structures and result in subacromial impingement.<sup>19</sup>

The cutoff point of  $\geq 0.2$  cm also coincides with the MDC<sub>90</sub> value of  $\pm 0.2$  cm, which is in agreement with the findings of a previous study.<sup>28</sup> Kumar et al,<sup>28</sup> in a study of 26 patients with stroke, reported a mean AGT difference of 0.4 cm and an MDC<sub>90</sub> value of  $\pm 0.2$  cm between affected and unaffected shoulders. A study of healthy individuals ( $n=32$ ; mean age 64 years, SD=11) showed a mean AGT difference of 0.1 cm (SD=0.18) (95% CI=0.03, 0.17) and MDC<sub>90</sub> value of  $\pm 0.07$  cm between right and left shoulders.<sup>32</sup> Based on the MDC<sub>90</sub> values from these studies, it could be predicted that a change of  $\pm 0.2$  cm in AGT distance measurements between affected and unaffected shoulders would be necessary to indicate an asymmetry that is not due to measurement error.

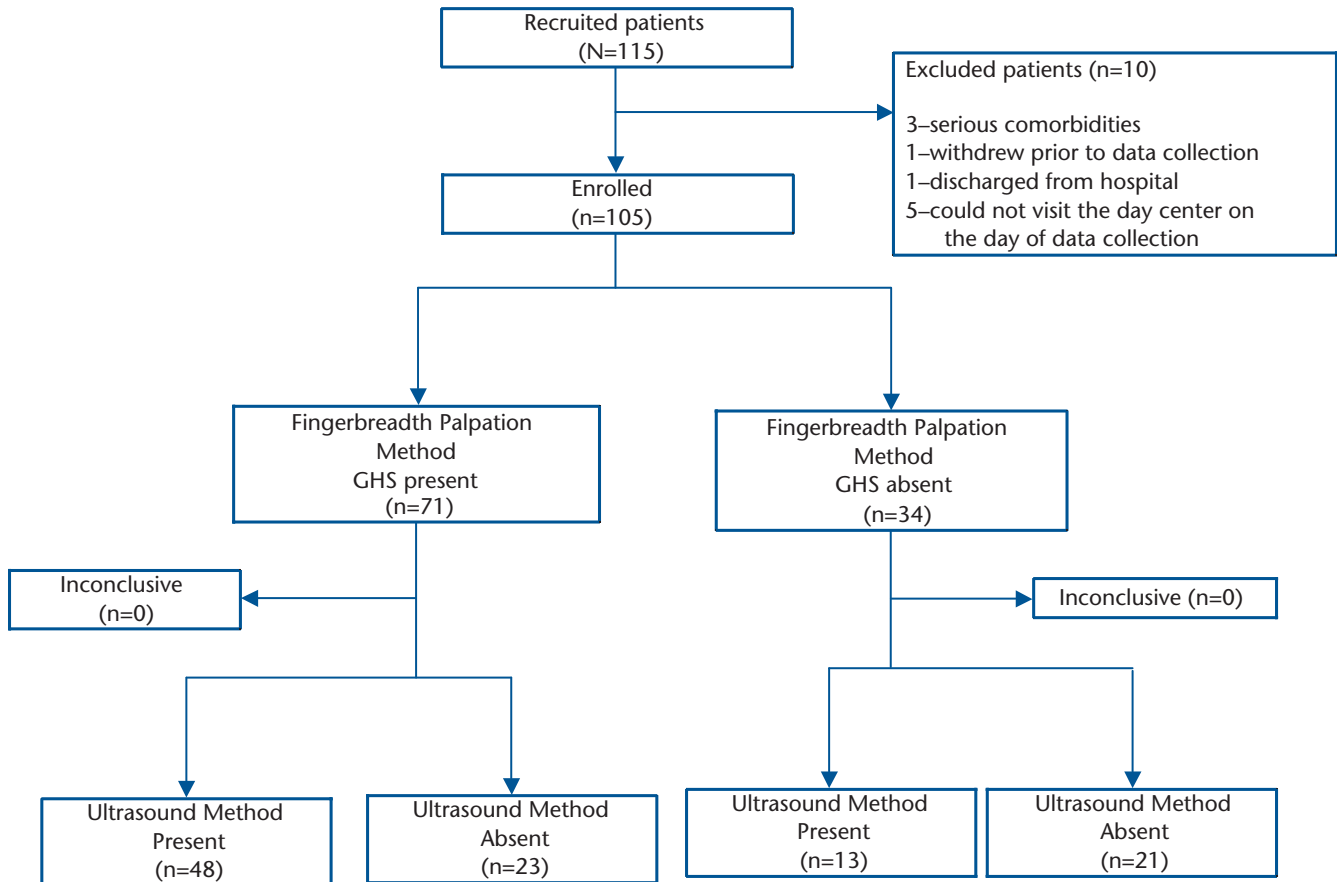
In this study, a mean AGT difference of  $\leq 0.5$  cm between affected and unaffected shoulders was observed in 33 patients, suggesting minor subluxation. It is critical to identify

minor subluxation in its early stage, as application of appropriate treatment can improve upper limb motor function.<sup>5,6</sup> Several studies have reported on the benefits of functional electrical stimulation in the prevention and treatment of GHS in early stages of rehabilitation<sup>5,41-43</sup> but not in patients with chronic stroke ( $>6$  months).<sup>6</sup> Findings from these studies suggest that GHS can be prevented by the application of appropriate treatment but that withdrawal of treatment can lead to subsequent subluxation, especially in patients with loss of voluntary control. In the United Kingdom, therefore, the latest national guidelines for stroke<sup>44</sup> recommend application of functional electrical stimulation to the supraspinatus and deltoid muscles for any patient with stroke who has developed, or is at risk of developing, GHS. Ultrasound has the potential advantage of identifying patients with even minor subluxation ( $\leq 0.5$  cm) and can provide objective measurements in the early stages of rehabilitation.

In contrast, the fingerbreadth palpation method has the potential advantage of being a quick, equipment-free method of identifying significant subluxation. However, it lacks the ability to detect early signs of subluxation,<sup>8</sup> is subjective,<sup>8,12,31</sup> and is insensitive, as it cannot detect differences of less than 0.5 cm.<sup>12</sup> Furthermore, the reported correlations for the concurrent validity of the fingerbreadth palpation method in comparison with radiographic measurements range from .69 to .76,<sup>29-31</sup> which are described as relatively low.<sup>45</sup> Limitations of the fingerbreadth palpation method could result in an underestimation of the true prevalence of GHS, which could contribute to the moderate correlation and relatively low sensitivity and specificity values for the ultrasound method found in this study. Due to resource, cost, and ethical con-



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**Figure 4.**

Flow diagram illustrating comparison between the ultrasound method and the fingerbreadth palpation method based on cutoff point of  $\geq 0.2$  cm acromion-greater tuberosity difference. GHS=glenohumeral subluxation.

straints, it was not possible to undertake radiographs of 210 shoulders.

Our study suggests that ultrasound measurements of AGT have potential value in the prevention and management of GHS in people with stroke. The technique is safe, noninvasive,<sup>15,16,46,47</sup> allows real-time measurements,<sup>48</sup> and requires limited training to produce reliable measurements of AGT distance.<sup>28,32,49,50</sup> Several other benefits of diagnostic ultrasound have been reported by recent studies of people with stroke.<sup>25,26</sup> A recent study demonstrated that subluxation occurred more frequently in patients (n=182) with a known presence of fluid in the subhumeral and subdeltoid bursae and in patients with reduced

functional capacity.<sup>25</sup> Ultrasound was used both as a diagnostic tool and to monitor the effectiveness of the exercise program targeting reduction of subluxation and bursal fluid. Similarly, another study investigated the association between GHS and soft tissue injuries in 39 people with stroke.<sup>26</sup> Similar to our study, the diagnosis of GHS was done by measuring the lateral AGT distance. The study showed that ultrasound complements the assessment of soft tissue injuries in shoulders of people with stroke.<sup>26</sup>

Given these findings, ultrasound has potential usefulness in both research and clinical practice. Clinically, ultrasound may be used to assess and monitor the effectiveness of treat-

ment interventions for GHS in people with severe paralysis, especially during the early stage of rehabilitation. It also has potential to diagnose soft tissue injuries in people with stroke, both with and without GHS, and thus can facilitate management of shoulder pain. In particular, it has utility as an outcome measure in intervention studies. The ultrasound method is objective, quantitative, and has the potential to detect even small changes in AGT distance measurements.

The current study had some limitations. First, there was a difference in the patients' starting position for the 2 methods. For the fingerbreadth palpation method, patients were in an upright sitting position with their

arms hanging freely by their sides and without arm support. In contrast, for the ultrasound method, the patients' forearm was placed in their lap. Patients with loss of motor control are potentially at risk of developing GHS, and gravity-dependent positions of the shoulder, therefore, should be avoided.<sup>3</sup> Kumar et al<sup>28</sup> developed a new standardized position with the forearm supported on a pillow, but the elbow itself remained unsupported to allow the effect of gravity. The study demonstrated excellent intrarater reliability and discriminant validity for the ultrasound method, suggesting it has the ability to diagnose GHS even when the forearm is supported. It was not possible to use this newly developed position for the fingerbreadth palpation method because there are no reports on reliability and validity for this method in this position. Second, patients were recruited from multiple sites, which meant 7 different physical therapists were involved in the assessment of GHS using the fingerbreadth palpation method. The reported interrater reliability (ICC) for the fingerbreadth palpation method is between .770 and .792.<sup>12</sup> This reliability might have contributed to greater variability and might have had some effect on the correlation between fingerbreadth palpation and ultrasound methods. Finally, the assessors conducting the fingerbreadth palpation method also were the clinical therapists involved in the routine care of study patients at the hospital. It is likely, therefore, that they were aware of the patients' subluxation status, which might have influenced their judgment on the day of data collection. However, patients (n=35) at the day center were not known to the clinical therapists.

In conclusion, on the basis of the AUROC curve value of 0.73, this study demonstrated a good level of agreement between the ultrasound

and fingerbreadth palpation methods. The ROC curve findings from this study indicate that a cutoff point of  $\geq 0.2$  cm could be used to determine the sensitivity and specificity of the ultrasound method to identify asymmetry between affected and unaffected shoulders and facilitate diagnosis of GHS. The ultrasound method has the potential advantage over the fingerbreadth palpation method of identifying patients with even minor subluxation ( $\leq 0.5$  cm). Ultrasound measurements provide ratio-level data and have clinical utility as an outcome measure in intervention studies. Future studies should investigate the diagnostic accuracy of the ultrasound method in the assessment of GHS in comparison with radiographic measurements. From an ethical perspective, investigation of diagnostic accuracy of the ultrasound method could be incorporated into intervention studies that routinely use radiographs to evaluate outcomes.

All authors provided concept/idea/research design and consultation (including review of manuscript before submission). Dr Kumar provided writing and data analysis. Dr Kumar and Ms Mardon provided data collection, facilities/equipment, and institutional liaisons. Dr Kumar and Dr Swinkels provided project management. Ms Mardon provided study participants.

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## Assessment of Glenohumeral Subluxation in Poststroke Hemiplegia: Comparison Between Ultrasound and Fingerbreadth Palpation Methods

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