RESEARCH ARTICLE

Quantitative Analysis of Scapular Winging Using Moire Topography

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Abstract

Objectives: Moire Topography (MT) is a non-invasive technique that uses patterned light projection and has been used to qualitatively characterize scapular winging. The purpose of the present study was to quantitatively characterize scapular winging using a novel method of MT.

Methods: A total of 20 shoulders in ten healthy subjects were analyzed. The mean age for subjects was 27.9 ± 1.0 years and mean BMI was 22.8 ± 2.8. Two scenarios were used to simulate scapular winging: Group 1) the hand-behind-back (HBB) position and Group 2) weighted scaption after a muscle fatigue protocol. A calibration object was used to validate the MT method. This was followed by a use of a control object with known dimensions (OKD) to evaluate subjects. The measured height (z) of the OKD with MT, as determined by the known dimensions of the OKD, was then compared to the scapula winging in Groups 1 and 2. Scapular winging was characterized by measuring the height or prominence (z) of the scapula.

Results: There were significant differences between the baseline scapular measurements and scapular winging measurements in both Group 1, 4.0 cm ± 1.3 (P=0.0004), and Group 2, 3.7 ± 1.6 (P=0.0178). Scapular winging was most prominent with the hand in the highest position on the back in Group 1 and at lower degrees of scaption (<60 degrees) in Group 2.

Conclusion: Quantitative characterization of scapular winging was achieved using a novel method using MT. Scapular winging was found at lower degrees of shoulder elevation. Future applications of this technique should focus on characterizing scapular winging in multiple planes in real-time and in patients with known shoulder pathology.

Level of evidence: III

Keywords: Moire topography, Quantitative, Scapula dyskinesis, Scapular winging

Introduction

Scapular winging is most often characterized by a prominence or protrusion of the scapula with attempted motion of the shoulder.[1] Shoulder pathology can often present with scapular winging.[2-6] Scapular winging is therefore typically recognized as a pathologic entity.

The relationships between scapular winging and shoulder pathology are not well understood. Qualitative methodologies which attempt to identify scapular winging, such as the Scapular Dyskinesis Test (SDT), suffer from low inter-rater reliability making comparative assessments difficult.[7-9] This is likely due to the subjective characterization of scapular winging which involve terminology such as "normal" or "subtle".[9]

Approaches which have been utilized to characterize scapular motion include biplane radiography, bone pin tracking, and surface marker tracking.[10-13] Although biplane radiography has succeeded in quantifying motion *in vivo* with high accuracy, it is expensive and exposes subjects and technicians to radiation.[10,11] Other studies have explored

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similar approaches in cadaveric specimens to better understand scapular orientation during glenohumeral motion.[14] However, these efforts have not specifically assessed *in vivo* scapular motion and winging.[14] The use of transcutaneous bone pins coupled with motion detectors has been shown to be successful in directly measuring scapular motion. However, this invasive approach makes serial studies over time difficult since bone pins cannot be reliably secured in the same location.[12] Surface marker tracking is less invasive and has been used to assess scapular motion, however with less accuracy.[10]

Moire topography (MT) has been used as a method of clinical diagnosis in topographic analysis since the 1970s.[15] MT is based on optical phenomena which enables the analysis of objects in three dimensions.[15] MT has been used in the characterization of spinal curvature in scoliosis patients and gait analysis.[15,16] Additional applications include the quantitative determination of palatal vault shapes in patients with Down syndrome and quantitative assessment of facial palsies.[17,18] More recent applications of MT have included the assessment of body postures and skin treatments.[19-21]

A form of MT was used by Warner *et al*[4] to identify scapular winging in patients with instability and sub-acromial impingement syndrome. The technique was more sensitive than routine clinical inspection. However, it was only qualitative in characterizing scapular winging.[4] Other pathologies of the shoulder have been shown to be better evaluated with quantitative imaging analysis.[22] Therefore, the purpose of this study was to quantitatively characterize scapular winging using a novel method of MT. Two scenarios were used to simulate scapular winging: Group 1) the hand-behind-back (HBB) position and Group 2) weighted scaption after a muscle fatigue protocol.[23] We hypothesize that scapular winging will be detected in the two aforementioned groups when compared to baseline measurements of the scapula.

Materials and Methods

After obtaining IRB approval, 10 healthy subjects volunteered to participate in the study. Informed consent was then obtained along with baseline shoulder range of motion (ROM), patient reported outcome measures (PROMs), Body Mass Index (BMI), and past surgical history. Participants were excluded from the study if their BMI was greater than 30 or if there was any active issues or dysfunction reported in their shoulders.

The mean age for subjects was 27.9 ± 1.0 years and mean BMI was 22.8 ± 2.8 [Table 1]. Five subjects were right-handed and five subjects were left-handed. Baseline mean shoulder range of motion in the scapular plane (scaption) for the dominant and non-dominate arms were respectively 170 ± 6 and 170 ± 5. No subjects reported any active problems or history of prior surgeries with their shoulders. All participating subjects reported baseline scores of 100 for the ASES and 12/12 on the Simple Shoulder Test.

Baseline Scapula Evaluation

Prior to any study intervention, baseline evaluation of subjects was performed to capture any pre-existing scapular winging. These images were obtained at 0 and 90 degrees of unweighted forward shoulder elevation in the scaption plane. Baseline winging was then used to correct for any winging which was measured during the HBB (Group 1) and fatigue protocol interventions (Group 2).

Table 1. Characteristics of study participants

Characteristic	N=10
Age (years)*	27.9 ± 1.0
BMI*	22.8 ± 2.8
Gender, n male (%)	5 (50%)
Hand dominance, n Right (%)	5 (50%)
Baseline Forward Flexion RUE (LUE)†	170 ± 6 (170 ± 5)
ASES score	100
Simple Shoulder Test (SST)	12

*Mean and standard deviation, †Values in degrees

Hand-behind-back

The hand-behind-back (HBB) position is an important motion of the scapula-thoracic joint associated with toileting and dressing.[24] It results in a prominence of the scapula consistent with what has been described as scapular winging.[4] Therefore, the HBB position was selected to model scapular winging in the present study. Analysis of the scapula with the arm in the HBB position was obtained in the following steps: 1) neutral position with the arm at the side, 2) the hand across the abdomen with the arm in the belly-press position, 3) the hand on the hip with the arm aligned in the coronal plane of the body, 4) the hand across the sacrum behind the back, 5) the hand at the highest vertebral level the subject was capable of reaching [Figure 1]. This formed Group 1.

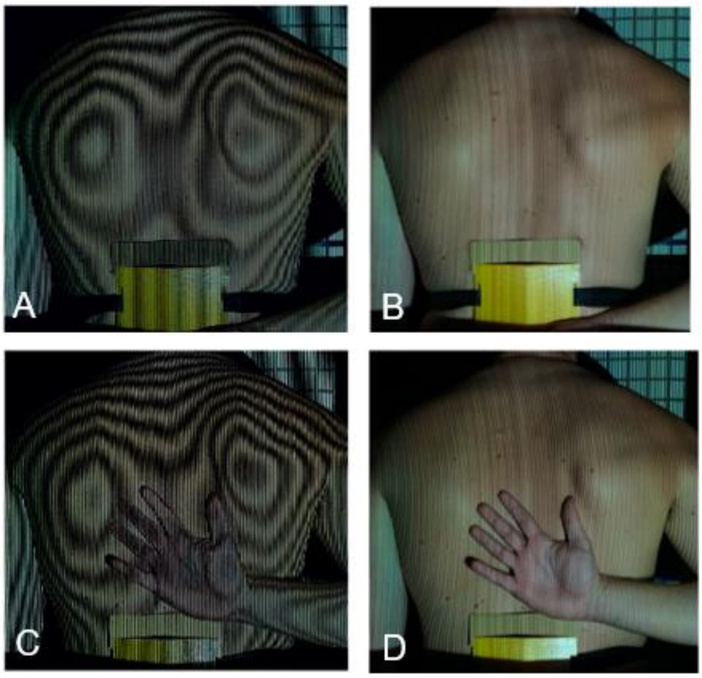

Figure 1. Group 1 hand across sacrum behind back. (A) Topographical images created with overlaid image of vertical lines. (B) Vertical lines projected on subject's back. Group 1 hand at highest vertebral level (C) Topographical images created with overlaid image of vertical lines. (D) Vertical lines projected on subject's back

Torque Measurements

A handheld dynamometer (Lafayette Hand-Held Dynamometer, Model 01165A, Lafayette, IN) was used to measure maximal isometric torque production during external rotation. Isometric torque measurements were made with the elbow at the side and the shoulder at 45 degrees of internal rotation. The elbow was maintained at 90 degrees of flexion. The forearm and wrist were maintained in neutral positions. The dorsal side of the wrist joint was placed on a pad that was connected to the dynamometer. Subjects warmed up with several submaximal contractions and one maximal isometric contraction of the shoulder performing external rotation. Subjects were then instructed to stand still, to keep their trunk from leaning forward or backward, and to push on the dynamometer with the dorsal side of their wrist using their shoulder external rotator muscles and keeping their elbow at their side against their body. The average resistance torque during a four-second maximal isometric contraction was then recorded. This value provided the baseline which was used to determine fatigue.

Fatigue Protocol

Scapular winging was simulated using an external rotation fatigue protocol which has been shown to produce a prominence of the scapula consistent with what has been described as scapular winging.[23] The fatiguing exercise utilized a medium resistance green Thera-band. One end of the Thera-band was attached to a fixed object while subjects held the other end. The subjects then performed external rotation of their shoulder, with their elbow at their side and flexed to 90 degrees, from 45 degrees internal rotation to neutral rotation against the resistance of the Thera-band. Subjects repeated this exercise at approximately one Hz and were asked to avoid elevating their arm or retracting their scapula. When subjects could no longer perform the task, their external rotation isometric torque production was re-measured with the dynamometer. If there was a decrease in torque from the baseline greater than 25%, the subjects were considered fatigued and stopped exercising with the Thera-band. If the decrease was 25% or less, subjects were not considered fatigued and continued exercising with the Thera-band until their torque production was reduced more than 25% from baseline.

Scapular Dyskinesis Test

Weighted scaption of the Scapular Dyskinesis Test (SDT) was utilized to accentuate scapular winging resulting from the aforementioned fatigue protocol.[9] After completion of the fatigue protocol, male subjects were asked to remove their shirts and females were asked to wear tops which allowed observation of the posterior thorax and scapula. Each subject then performed five positions of bilateral active, weighted shoulder abduction in the scapular plane (scaption). This formed Group 2. Shoulder motion was performed at 30, 60, 90, 120, and 150 degrees [Figure 2]. Range of motion was measured with a hand-held goniometer. Tests were performed with subjects grasping 2.3kg (5lb) dumbbells in each hand.

Moire Topography

MT is accomplished by projecting an image of an equal spaced gradient of vertical lines onto an object which is then observed through the gradient.[15] The resulting fringes are formed by the interference of the two sets of gradients.[15] This enables topographic analysis.

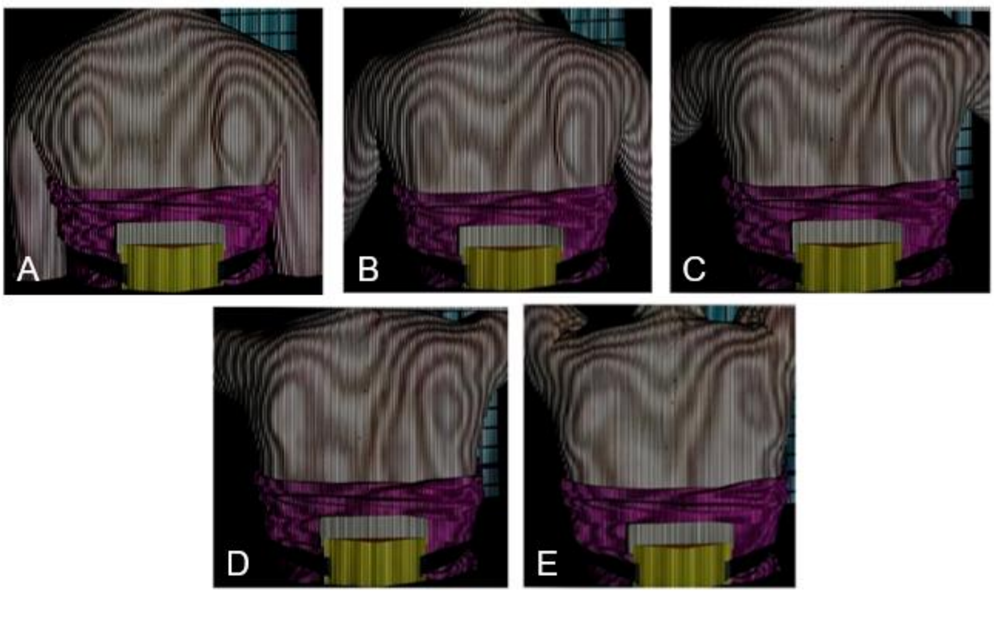

Figure 2. Group 2 demonstrating five positions of bilateral active, weighted shoulder abduction in the scapular plane (scaption) at 30 degrees (A), 60 degrees (B), 90 degrees(C), 120 degrees (D), and 150 (E) degrees

Geometric Validation

A calibration object with an adjustable z-dimension was used to validate the MT technique used in the present study [Figure 3]. Dimensions of the calibration object were 96mm width and 158mm length. The calibration object was then imaged at 11 different heights ranging from 2mm to 68.5mm. The height (z) of the calibration object was measured manually with a ruler. These values were then compared to the heights determined using Moire topographic images. Topographic images were created by overlaying the same image of vertical lines projected onto the calibration object in a custom software program (MATLAB, Natick, USA). MT determined the calibration object height (z) using the formula $z = \lambda bn/d$ where λ is the spacing of the overlaid lines, b is the distance between the camera and the calibration object, n equals the number of fringes counted between the origin and apex of the calibration object, and d is the distance between the projector and the camera. An intraclass correlation coefficient (ICC) was calculated to be excellent at 0.98 when comparing the heights of the calibration object measured manually to the heights calculated using the MT method in the present study [Figure 3].

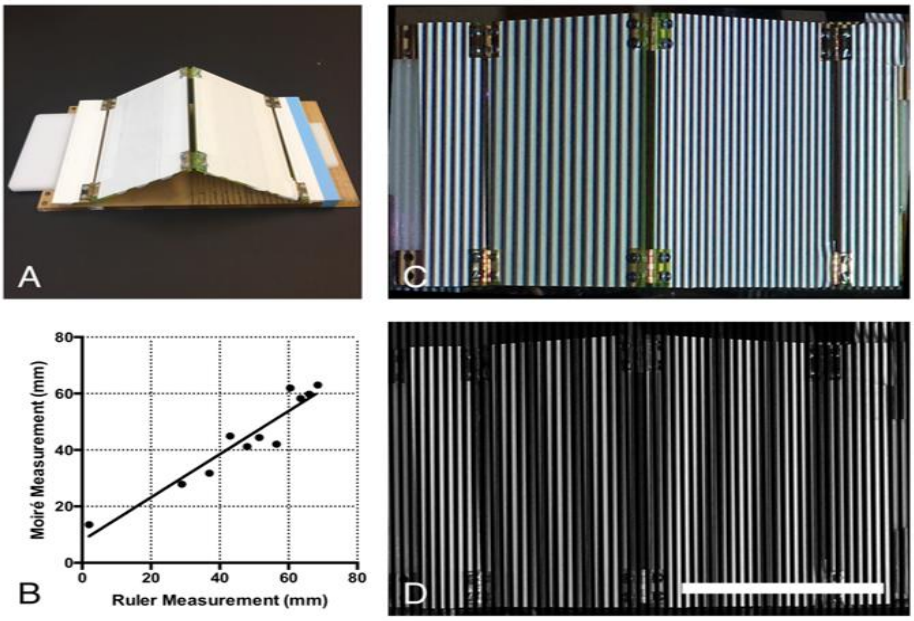

Figure 3. (A) Symmetric calibration object was used to validate the MT technique. (B) Graphical depiction of the correlation between MT derived height measurements of the calibration object and manual ruler measurements. (C) Vertical lines projected onto calibration object. (D) Dark areas on calibration object represent MT fringes which were used to determine calibration object height. Scale bar in lower right corner represents 10 cm

To determine scapula winging in subjects, a camera (Apple iPhone 11, Cupertino, CA, USA) was placed one meter from and facing directly toward the subject's back. A projector (Powerlite 95, Epson, Suwa, Japan) was placed on standard table 0.3meters from the camera along an axis angle of 73 degrees from the normal [Figure 4]. Care was taken to have the camera and projector at the same height. A standard image of vertical lines was then projected onto the subject's back with spacing of 3-4mm. The projected line thicknesses were varied to ensure all lines were equal in thickness on the subject's back. The degree of scapular winging was determined using Python (Python Software Foundation, Delaware, USA) and Pixlr (AutoDesk, San Rafael, USA) software. The fringes which resulted from the overlay of gradient image of vertical lines created a topographical map on the subject's back. Spacing of the overlaid gradient image of vertical lines was then adjusted until the observed number of fringes on each side of the control object of known dimension (OKD) were equal. The height was determined by extrapolating the number and pattern of fringes formed by the OKD and the subject's scapula. The degree of scapular winging was characterized by determining the prominence or height of the scapula.

Geometric Reference with OKD

Validation of the MT technique with the calibration object enabled use of an object of known dimensions (OKD) to serve as a reference in the study. The calibration objection and OKD were the same geometric shape and also had similar dimensions. Calibration object width was 96mm and its length was 158mm. The heights of the calibration object ranged from 2mm to 68.5mm. OKD dimensions were 30mm height, 80mm width, and 140mm length. OKD height (z) was calculated again using the formula $z = \lambda bn/d$ where λ is the spacing of the overlaid lines, b is the distance between the camera and the OKD, n equals the number of fringes counted between the origin and apex of the OKD, and d is the distance between the projector and the camera.

Statistical Analysis

Non-parametric statistical comparison between groups was performed with Wilcox ranked signed and Mann Whitney U tests for data analysis. SPSS (ver 18.0) and Microsoft Excel (2019) were used for data analysis and storage. Mean and standard deviation (±STD) were reported for all data. Statistical significance was set to P<0.05.

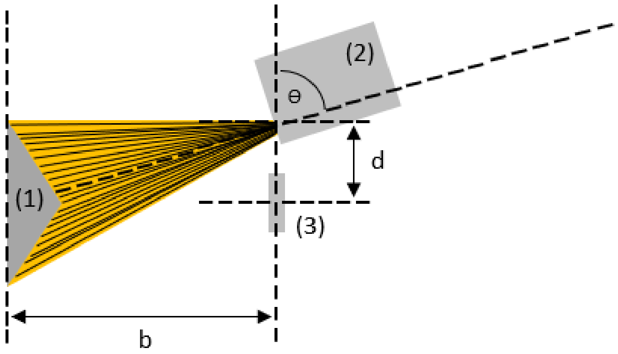

Figure 4. MT set-up with projector and camera at the same level. (1) object of known dimension (OKD), (2) projector, (3) camera, b = the distance between the camera and the OKD, d = the distance between the projector and the camera. Θ = axis angle of 73 degrees from the normal

Results

After validation with the calibration object, the fringe pattern produced by the OKD was used as a reference for quantitively characterizing scapular winging in Groups 1 and 2. Furthermore, the number and fringe patterns produced by the OKD were similar in number to those in Groups 1 and 2 which reflected the quantitative values of scapular winging determined by MT.

Baseline scapular winging was present in all subjects [Table 2]. There were significant differences between the baseline scapular measurements and scapular winging measured in both Group 1, 4.0±1.3cm (P=0.0004), and Group 2, 3.7±1.6 (P=0.0178). The mean difference between baseline and measured scapular winging was 1.4cm in Group 1 and 1.3cm in Group 2. Scapular winging was most notable with the hand in the highest position on the back in Group 1 and at lower degrees of scaption in Group 2 (<60 degrees) and [Table 3].

Discussion

This study quantitatively characterized scapular winging using a novel method of MT through use of a calibration object and an OKD. Once the MT method was validated with the calibration object, the control OKD enabled scapular winging to be quantitatively measured in both study groups. There were significant differences between the baseline measurements and the scapular winging in Groups 1 and 2. The results of the present study compare favorably to previous work.

Table 2. Baseline Scapular Winging*

	LUE	RUE
Neutral (0 degrees)	2.3 ± 0.4	2.9 ± 1.1
Abduction (<90 degrees)	2.5 ± 0.9	3.9 ± 1.2

*Winging in cm, Mean values ± SD

Table 3. Scapular Winging

	LUE	RUE
Group 1: HBB‡	3.6 ± 1.3	4.3 ± 1.2
Group 2: Fatigue (Raise)	2.9 ± 1.6	3.6 ± 1.6
Group 2: Fatigue (Lower)	3.1 ± 1.4	4.1 ± 1.6

*Winging in cm, ‡ Hand-behind-back, Mean values ± SD

Warner *et al*[4] utilized a qualitative MT technique to objectively characterize scapular winging in 29 patients with instability and sub-acromial impingement syndrome. The authors utilized qualitative MT fringe pattern differences to analyze scapular winging. Characterization was based on degree symmetry, increased topography, and gross inspection. Nearly two-thirds of patients with anterior shoulder instability and 100% of patients with impingement syndrome demonstrated either asymmetry, increased topography, or "frank" scapular winging on gross inspection during repetitive forward flexion. Similar to the present study, scapular winging was noted at lower degrees of shoulder elevation (<60 degrees). Other authors have also found scapular winging to be more pronounced at lower degrees of shoulder elevation.[4,25] It has been suggested that shoulder function, below the horizontal plane, results in a mechanical disadvantage to the serratus anterior. Therefore, scapular winging is more easily detected with shoulder positions below the horizontal plane.[25]

McClure et al[9] evaluated interrater reliability of the scapular dyskinesis test (SDT) in 142 overhead collegiate athletes. Each subject completed 5 repetitions of bilateral, active, weighted shoulder flexion and abduction which constituted the SDT tasks. Similar to the present study, subjects were excluded if they reported a history of any shoulder pathology or surgery. In addition, all subjects had BMI values ≤30 which is similar to the present study. The authors found moderate interrater reliability using the SDT to classify scapular motion. However, unlike the present study, McClure et al[9] provided only qualitative characterization. Scapular motion was classified as normal, subtle dyskinesis, or obvious dyskinesis.[9]

Weon *et al*[26] quantitively defined a threshold for scapular winging as a distance of at least 2 cm between the thoracic wall and inferior angle of the scapula using a scapulameter in 19 subjects. The threshold of 2cm was selected because this was the minimum amount of winging in subjects with 'fair minus' or lower grade muscle strength of the serratus anterior. The authors found these measurements demonstrated high test-retest reliability.[26]

Prior to this study, no previous authors had provided quantitative data for scapula winging nor suggested a relationship between the degree of winging and strength of the serratus anterior muscle. The threshold of 2cm reported by Weon *et al*[26] is greater than the results of the present study which were 1.4cm in Group 1 and 1.3cm in Group 2. However, different methods were used by Weon *et al*[26] to elicit scapular winging and may explain why the present study had lower values. It is possible, the method used by Weon *et al*[26] to elicit scapular winging produced a more fatigued serratus anterior than the present study and therefore produced greater scapular winging. Another possible explanation could be the present study's method for measuring scapular winging with the OKD. The OKD was placed in the lumbar spine area of subjects. Consequently, the OKD and scapula may have been different distances from the projector. This could have resulted in an underestimation of the scapular winging. Finally, Weon *et al*[26] initially measured but did not report on baseline scapular winging in their study population. Thus, their scapular winging threshold of 2 cm may have been less if baseline scapular winging was also considered in their analysis.

There are several limitations to the present study. First, the technique was limited to only measuring the prominence or height of the scapula. Therefore, any abnormal scapular motion or winging in other planes was not measured. In addition, it is possible that the most prominent feature, with the greatest height, was not the scapula in all phases of motion. Thus, the true abnormal motion of the scapula or winging may have been underappreciated. Second, scapular winging was only characterized at static points within the scaption plane. Thus, any scapular winging which occurred beyond or between these points was not captured. Third, we did not perform any manual measurements of scapula like those performed by Woen *et al*[26]. In addition, we did not compare our MT method with another technique such as biplane fluoroscopy. However, we believe the OKD served as reliable reference for determining the prominence or height of the scapula given the geometric validation data presented for the calibration object. Fourth, this study characterized scapula winging in simulated conditions with young healthy subjects and low BMI values. It has been previously reported that visualizing scapular winging in patients with BMI values greater than 30 becomes difficult.[27] Thus, our MT methods may not provide meaningful characterization of scapular winging in obese or morbidly obese patients with true scapular motion pathology. Finally, this study evaluated twenty shoulders in ten subjects which is a smaller study population than some previously published work.[4,9] Thus, this study possesses limitations inherent to smaller study populations which include lack of power and generalizability of findings. Low statistical power arising from small sample sizes can impact the likelihood that a statistically significant finding represents a true effect. However, research in this area is sparse with multiple studies evaluating glenohumeral scapula motion in as few as five to eight subjects.[11,28] Furthermore, our results compared favorably to studies which had larger populations.[4,9]

The present method of MT could be clinically useful for several reasons. Although prior methods have utilized MT to characterize scapular winging, this characterization has been qualitative.[4] Unlike the present study, no control object or landmark with a known height or elevation has been used as a reference. Another unique aspect of the present MT technique is its non-invasive quantization of scapular winging. Unlike prior methods which have employed manual measurement of scapular winging, the present MT technique does not require any direct contact with subjects.[26] Therefore, there is no risk that scapular winging could be disrupted by manual measurement. In addition, the present method of MT can vary the thickness and distance between vertical lines of the projected gradient image according to the desired precision of measurement. Lastly, the present MT technique lends itself to the possibility of measuring real-time scapular winging which would be very difficult and impractical with manual techniques.

Conclusion

In conclusion, this study characterized a novel method using Moire Topography as a quantitative tool, which was used to diagnose and characterize scapular winging. Scapular winging was found at lower degrees of shoulder elevation consistent with previous work.[4,25] In addition, the quantitative assessment of scapular winging compared favorably to previously published results.[26] Future application of this technique should focus on characterizing scapular winging in multiple planes in real-time and in patients with known shoulder pathology.

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