**3D measurement of clavicular and scapular orientations: the association with clinical characteristics and responsiveness to scapular repositioning in patients with neck pain**

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**1. Introduction**

Except for the sternoclavicular joint, the attachments of scapula and clavicle to the axial skeleton are muscular, and in turn, the scapula provides attachment to several muscles of the upper limb. Upper limb activities provoke neck pain in up to 80% of patients with cervical disorders (Osborn and Jull, 2013; See and Treleaven, 2015), which reflects the potential for adverse loading on cervical structures via muscles such as levator scapulae and to a lesser extent the upper trapezius (Behrsin and Maguire, 1986; Johnson et al., 2008). Impaired axio-scapular muscle function may affect scapular position in individuals with neck pain (Zakharova-Luneva et al., 2012; Castelein et al., 2015; Petersen et al., 2016), and has been suggested as potential risk factors for neck pain (Cagnie et al., 2014; Yildiz et al., 2019).

An ideal scapular position is generally considered to be that it is located from the level of T2 to T7-9 spinous processes, it lies flat against the thorax, and is internally rotated 30° to 45° from the coronal plane and anterior tilted 10° to 20° and upwardly rotated 10° to 20° from the vertical plane (Ludewig and Cook, 2000; Sayeed and Darling, 2007; Haneline et al., 2008). In patients with chronic non-specific neck pain, different patterns of clavicular and scapular orientations have been documented including reduced retraction of the clavicle and increased downward rotation, and protraction of the scapula (Szeto et al., 2002; Helgadottir et al., 2011; Selvam and Balasuburamaniam, 2016). Nonetheless, there is considerable inter-individual variability in scapular orientation. Several studies have investigated the effects of correcting scapular orientation to a more anatomically correct position and showed immediate changes in neck pain and/or cervical range of movement (Van Dillen et al., 2007; Andrade et al., 2008; Ha et al., 2011). In these studies, scapular correction or repositioning was performed in one direction only, e.g., scapular elevation (Van Dillen et al., 2007; Andrade et al., 2008) or scapular upward rotation (Ha et al., 2011). While the repositioning helped many, some patients did not respond or had clinically irrelevant improvement (Van Dillen et al., 2007). Identifying subgroups presenting with similar shoulder girdle (clavicle and scapula) orientations may help clarify if a positive response to scapular repositioning relates to a specific position or combination of scapular positions and similar clinical characteristics. Subgrouping of patients with neck pain based on shoulder girdle orientations, clinical characteristics and the response to scapular repositioning might be helpful in identifying the altered clavicular and scapular postures most relevant to chronic non-specific neck pain. This might also assist clinical decision-making for specific rehabilitation aimed at improving scapular posture and muscle function.

The aims of this study were: (i) to identify subgroups based on the 3D measurement of the resting clavicular and scapular orientations within a sample of individuals with chronic non-specific neck pain with altered scapular alignment and (ii) to investigate if there were any differences in the subgroups with respect to clinical characteristics and the response to manual scapular repositioning. It was hypothesized that (i) subgroups would be differentiated based on the 3D clavicular and scapular orientation and (ii) there would be differences between the subgroups with respect to clinical characteristics and responses to the scapular reposition test.

**2. Methods**

*2.1. Participants*

This cross-sectional study is part of a larger research project investigating scapular dysfunction in patients with neck pain (Grant No. PHD/0153/2560) (Wannaprom et al., 2021). The original sample included 144 eligible participants with neck pain with altered scapular orientations. Of these, 107 demonstrated a clinically relevant improvement in either neck pain or range of rotation or both, following manual scapular repositioning (responsive group) and 37 had no relevant improvement (non-responsive group) (Wannaprom et al., 2021). In the present study, all participants in the non-responsive group (n = 37) were invited to participate whereas participants in the responsive group (n = 107) were invited using a random number generator. A ratio of 1:1 was sought between the responsive and non-responsive groups, that is, an even distribution of participants in each group. The sample size was considered based on a minimum sample size requirement for cluster analysis (no less than 2^k cases, k = five variables) (Formann, 1984). A minimum of 32 participants was required for the study.

All participants with non-specific neck pain (i.e., unidentified pathoanatomical cause) were recruited between May 2020 and February 2021 from local hospitals, physical therapy clinics, the university and community by advertising through flyers, posters and social networks (e.g., Facebook and Instagram). Inclusion criteria for eligible participants were: aged between 18 and 59 years; chronic neck pain (≥ 3 months); an average pain intensity of ≥ 3 on a 0-10 cm Visual Analog Scale (VAS) in the past week; a current Neck Disability Index (NDI) score of at least 10/100 (Vernon and Mior, 1991; Uthaikhup et al., 2011); scapular alignment which was altered from the anatomical neutral position and was ipsilateral to the more painful side of neck pain (Wannaprom et al., 2021). The neutral position was defined as the scapula situated parallel to the spine approximately 2 inches from the midline of the thorax, between the second through seventh ribs, rotated forward (in the vicinity of 30 degrees), inclined slightly inferiorly-laterally, without any prominence of scapular angle and border (O'Leary et al., 2015). Participants were excluded if they reported a history of head and neck injury, shoulder problems, neurologic conditions and any musculoskeletal problems that could affect the scapular position.

The study was approved by the Institution’s ethical review committee for research in humans (No. AMSEC-62EX-049) and was conducted in accordance with the declaration of Helsinki. All eligible participants signed a written informed consent statement prior to entering the study.

*2.2. Measurements*

*2.2.1. Questionnaires*

A questionnaire was developed to gather information on demographics, characteristics of neck pain (such as location, duration and intensity of neck pain) and the presence of headache. The NDI was used to measure self-rated disability (Vernon and Mior, 1991; Uthaikhup et al., 2011). The NDI was scored as a percentage with a higher score indicating greater perceived disability.

*2.2.2. Response to manual scapular repositioning*

The procedure for manual scapular repositioning and criteria for a positive response are described in detail elsewhere (Wannaprom et al., 2021). In brief, manual repositioning was performed on the ipsilateral or the more painful side of the neck in relation to the scapular’s rotational (upward/downward, anterior/posterior, internal/external) translational (superior/inferior, protraction/retraction) positions. The measures of cervical range of motion (CROM) in rotation and neck pain intensity were taken twice in each of the resting (uncorrected scapular position) and the modified (corrected) scapular position using the CROM instrument (Performance Attainment Associates, USA). Participants with average change scores in pain of > 2 points on an 11-point numerical rating scale (NRS) and/or ≥ 7 degrees in cervical rotation range were considered to have a positive response to scapular repositioning. The cut-off scores for pain and cervical range were based on the differences that are regarded as clinically important (Pool et al., 2007; Audette et al., 2010; Young et al., 2019).

*2.2.3. 3D measurement of the clavicular and scapular orientations*

 As the orientations of the clavicle and the scapula can be difficult to determine with accuracy by visual observation, this study used quantitative three-dimensional (3D) measures of clavicular and scapular positions (Warner et al., 2012, 2015). The 3D orientations of the clavicle and scapula were captured using a 10-camera motion analysis system (Eagle cameras, Motion Analysis Corporation, Santa Rosa, CA, USA), at a sampling frequency of 120 Hz, filtered using a fourth-order Butterworth low-pass filter, with a cutoff frequency of 8 Hz. The 3D measurement procedures were conducted according to previous studies (Warner et al., 2012, 2015). An acromion marker cluster (AMC), a valid and reliable method, was used to obtain the clavicular and scapular orientations (Warner et al., 2012, 2015) (Figure 1A). The center of the AMC was placed on the flat portion of the acromion with one end pointing anterior to the scapular plane and the other following the spine of the scapula. Retroreflective markers were attached to the anatomical landmarks at the sternal notch, C7 and T8 vertebrae following International Society of Biomechanics (ISB) guidelines (Wu et al., 2005) (Figure 1B). Retroreflective markers were also attached on the lower ribs, the humerus (i.e., at medial and lateral epicondyles, 5 cm. above lateral epicondyle of humerus), and ulna and radial bones (at 5 cm. above olecranon process, styloid processes and 5 cm. above styloid processes) (Figure 1B). A calibration wand was used to determine the location of the sternoclavicular landmark with respect to the thorax and the acromioclavicular and scapular anatomical landmarks with respect to the AMC (Warner et al., 2012, 2015). Intra-rater reliability of the 3D measurement of the clavicular and scapular orientations was conducted in eight participants and the intraclass correlation coefficients (ICCs) were excellent (range 0.81 to 0.94).

Participants stood in a relaxed position with their feet hip-width apart. A standard instruction was given by an assessor “Assume an upright standing position looking straight ahead, allowing your shoulders, arms and hands to relax”. The 3D measurement of the clavicle and scapula was recorded in this resting posture for 10 seconds. The 3D data was analyzed for the more painful side of neck pain. The assessor was blinded to participants’ characteristics.

*2.3. Data management and statistical analysis*

The 3D data collection was conducted using relevant kinematic modeling software. The software which contained commands to enable the creation of local coordinate systems, the conversions of coordinates from a global to local coordinate system, and a local to global coordinate system was used for the calculation of Euler angle rotations (Wu et al., 2005; Teece et al., 2008; Warner et al., 2015). The orientation of the clavicle with respect to the thorax was determined through a rotation sequence of the plane of elevation (+ve) / depression (-ve) (Y), protraction (+ve) / retraction (-ve) (Z).The orientation of the scapula with respect to the thorax was determined following a rotation sequence of the plane of internal rotation (+ve)/external rotation (-ve) (Y), upward rotation (+ve)/downward rotation (-ve) (X) and posterior tilt (+ve)/anterior tilt (-ve) (Z). All upward rotation angles were multiplied by -1 to obtain more intuitively interpretable data, with an increase in value corresponding to upward rotation of the scapula.

 All analyses were conducted using SPSS statistical software package. A significance level was set at 0.05. The Shapiro-Wilk test was used to determine normality of data. A hierarchical agglomerative cluster analysis using Ward’s clustering method with squared Euclidean distance was conducted to identify subgroups based on the 3D clavicular (protraction/retraction, elevation/depression) and scapular (internal/external, upward/downward rotation, anterior/posterior tilt) data. In Ward’s method, the distance between two clusters were merged based on the error sum of square (ESS) values between the clusters added up over all the variables (Murtagh and Legendre, 2011). The optimal cluster solution was identified based on statistical and theoretical criteria. We examined the dendrogram and agglomeration coefficients. To validate our cluster groupings, discriminant function analysis with cross-validated classification was performed to determine accuracy of cluster group classification. An independent t-test was used to assess how the cluster subgroups in the cluster solution differed from one another on the clustering variables (the 3D clavicular and scapular data).

Cluster (subgroup) differences with respect to response to manual scapular repositioning, clinical characteristics and demographic data were then examined with independent t-tests for continuous variables and chi-square test for categorical variables. Effect sizes were calculated for independent t-tests using Cohen’s d (0.2 small, 0.5 medium, 0.8 large) and for chi-square using Cohen’s w (0.1 small, 0.3 medium, 0.5 large) (Cohen, 1988).

**3. Results**

*3.1. Participants*

Fifty-eight participants (29 responsive and 29 non-responsive to scapular repositioning) volunteered to take part in the present study. Of the 37 non-responsive participants in the original cohort, eight declined to participate due to personal reasons. Participants comprised 63.8% women; mean age 38.3 ± 10.2 years; and body mass index 22.7 ± 3.0 kg/m2. Neck pain intensity was 4.1 ± 0.5 (0-10 VAS); neck pain duration was 29.3 ± 12.1 months; and neck disability was 29.0 ± 9.4 (%NDI).

*3.2. Subgroups of 3D clavicular and scapular orientations*

 Table 1 presents the mean values of retraction and elevation of the clavicle and internal rotation, downward rotation and anterior tilt of the scapula for all participants and subgroups 1 and 2. The resultant dendrogram of the cluster analysis of 3D clavicular and scapular orientation measures using a Ward's hierarchical method identified two subgroups: subgroup 1 = 26 and subgroup 2 = 32 (Figure 2). The discriminant function analysis with cross-validated classification demonstrated that the 3D clavicular and scapular orientations were able to correctly classify 87.9% of two subgroups (88.5% of cluster 1, 87.5% of cluster 2) (Wilks’Lamda = 0.4, *p* = 0.001).

Significant differences were found between subgroups for all clustering variables (*p* < 0.05) (Table 1). Participants in subgroup 1 had greater clavicular retraction and scapular downward rotation whereas participants in subgroup 2 had greater clavicular elevation and scapular internal rotation and scapular anterior tilt (*p* < 0.05).

*3.3. Clinical characteristics and responses to manual scapular repositioning between two subgroups*

Table 2 presents the participants’ demographics, clinical characteristics and response to scapular repositioning in subgroups 1 and 2. Participants in subgroup 1 had more frequent reports of headache and more pain in either the upper or whole neck (*p* < 0.01). Participants in subgroup 2 had more pain in the lower neck (*p* < 0.001). There were no significant differences between the subgroups for demographics, neck pain intensity, duration and disability (*p* > 0.05). Most participants in subgroup 1 (88.5%) were responsive to manual scapular repositioning whereas in subgroup 2, most (81.2%) had no relevant improvement.

**4. Discussion**

Identifying subgroups of patients with neck pain with altered alignment of the shoulder girdle may assist decisions on clinical relevance. The cluster analysis based on the 3D measures of clavicular and scapular orientations identified two predominant subgroups (with large effect size) according to orientations of altered shoulder girdle alignment. Forty-five percent of participants with neck pain (subgroup 1) displayed greater clavicular retraction and scapular downward rotation and 55% (subgroup 2) displayed greater clavicular elevation, scapular internal rotation and anterior tilt. Some distinguishing clinical characteristics were evident between subgroups (large effect sizes). Most participants in subgroup 1 reported more pain in the upper neck, whereas most participants in subgroup 2 reported more pain in the lower neck. In addition, 73% of participants in subgroup 1 reported headache whereas headache was reported by only 28% of participants in subgroup 2. There were no other differences in neck pain characteristics (i.e., neck pain intensity, duration and disability). In relation to response to manual scapular repositioning, most participants who responded positively were in subgroup 1 (23/26) and the majority with no response were in subgroup 2 (26/32).

Combined, the results suggest that neck pain patients with scapular downward rotation are more likely to present with upper neck pain and headache and respond positively (either pain or cervical rotation range) to scapular repositioning whereas those with a more protracted and anteriorly tilted scapula are more likely to have pain in the lower neck and have no clinically relevant improvement to scapular repositioning. This may imply that a downwardly rotated scapular position is potentially more pertinent in relation to increased mechanical loading and compressive forces on the cervical spine, leading to neck pain than a protracted scapular position. The specific scapular orientations along with the characteristics of neck pain identified in this study may assist in identifying patients who would benefit from scapular rehabilitation in clinical practice. Visual observation of the scapula has been demonstrated as a reliable clinical tool for assessing scapular position and movement (Struyf et al., 2014; O'Leary et al., 2015). Although this study primarily focused on 3D measurement of the clavicle and scapula, the results may direct clinicians when observing the scapula. Nevertheless, altered scapular positions must be considered in relation to the patients’ symptoms and responses to other clinical tests.

Supporting the results of this study, scapular downward rotation is commonly observed in patients with neck pain (Ha et al., 2011; Helgadottir et al., 2011), and in many, neck pain and/or neck rotation range of motion improve with scapular repositioning (Ha et al., 2011). Some patients do not respond to scapular correction (Van Dillen et al., 2007; Wannaprom et al., 2021) which might be explained by the findings of this study. The position of an elevated clavicle together with an internally rotated and anteriorly tilted scapula is often associated with a shortened pectoralis minor and weakness of serratus anterior muscles (Ludewig and Cook, 2000; Sahrmann, 2002). The increased clavicular elevation can also be associated with tightness of the sternocleidomastoid (SCM) muscle and increased activity of the upper trapezius muscle (Sahrmann, 2002; Ludewig and Braman, 2011). This may contribute to trigger points and pain over the neck and shoulder girdle (Fernández-de-las-Peñas et al., 2012; Muñoz-Muñoz et al., 2012). However, the anatomical attachment of these muscles suggests they are less likely to contribute to increased mechanical forces on the cervical spine, as compared to the downward rotated scapula. The downward rotated scapula is typically associated with a shortened and overused levator scapulae, lengthened upper trapezius muscle and weakness in the tripartite trapezius and serratus anterior muscles (Sahrmann, 2002). The retracted clavicle may be associated with the relative motion of scapular external rotation (Teece et al., 2008), which is produced by the upper trapezius (Fey et al., 2007). The levator scapulae attaches directly to the C1 to C4 cervical transverse processes and resolution of its forces results in compressive force on the spine (Behrsin and Maguire, 1986; Johnson et al., 2008). Overuse of the levator scapulae may therefore place unwanted strain on the upper cervical joints, which would be consistent with the more frequent report of headache and pain more in the upper neck in this subgroup.

There are some limitations to this study. The results of the cluster analysis are dependent upon the sample of data used. Although the minimum sample size required was obtained for the current study, further research with a larger sample size may help confirm the results. Anatomical landmark palpations might also lead to measurement error. Additionally, the relative movement between the clavicle and the scapula may cause some potential errors during measurements. The 3D measurement of the scapula was conducted only on the ipsilateral side of neck pain and future research should consider responses on both sides. Additionally, there were no measures of cervical musculoskeletal neuromuscular, sensorimotor or articular function, including axio-scapular muscle tests in this study. Future research including these measures would better characterize the features associated with relevant scapular positional anomalies. Additionally, further research should focus on how the subgroups identified could direct rehabilitation to improve clinical outcomes.

**5. Conclusion**

Two subgroups of patients with neck pain were identified on the basis of 3D measures of clavicular and scapular orientations. Participants in subgroup 1 displayed greater clavicular retraction and scapular downward rotation whereas participants in subgroup 2 showed greater clavicular elevation and scapular internal rotation and anterior tilt. The clinical features which distinguished subgroup 1 were the higher incidences of headache, more pain in the upper cervical region and positive responses to scapular repositioning. The results suggest that patients with neck pain with altered alignment of the shoulder girdle should not be regarded as a homogenous group in either clinical practice or in future clinical trials on scapular rehabilitation.

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| Figure 1 A): Acromion marker cluster B) Retro-reflective markers on anatomical landmarks (IJ = sternal notch, C7 = spinous process of the C7 vertebra, T8 = spinous process of the T8 vertebra, ME = medial epicondyle, LE = lateral epicondyle, OP = olecranon process, US = ulnar styloid process, RS = radial styloid process) |

|  |
| --- |
|  |
| Figure 2 Dendrogram of hierarchical clustering algorithm. Large changes of distance show the best cut at value of 19.5 for two clusters which indicated by dotted line.  |

**Table 1** The 3D clavicular and scapular orientations in all participants and subgroups 1 and 2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | All (n = 58) | Subgroup 1 (n = 26) | Subgroup 2 (n = 32) | *p*-value\* | Effect sizeCohen’s d |
| Clavicle (degrees) |  |  |  |  |  |
|  Protraction (+ve)/Retraction (-ve) | -15.7 ± 4.5 | -17.2 ± 3.7 | -14.5 ± 4.8 | **0.02** | 0.63 |
|  Elevation (+ve)/Depression (-ve) | 5.0 ± 4.8 | 1.4 ± 2.8 | 7.8 ± 4.2 | **<0.001** | 1.79 |
| Scapula (degrees) |  |  |  |  |  |
|  Internal (+ve)/External rotation (-ve)  | 31.3 ± 7.3 | 28.5 ± 5.6 | 33.6 ± 7.8 | **0.01** | 0.75 |
|  Upward (+ve)/Downward rotation (-ve)  | -3.3 ± 5.4 | -7.2 ± 3.6 | -0.1 ± 4.4 | **<0.001** | 1.77 |
|  Posterior (+ve)/Anterior tilt (-ve)  | -9.9 ± 4.1 | -7.6 ± 3.8 | -11.8 ± 3.3 | **<0.001** | 1.18 |

Data are presented as mean ± SD.

\* Independent t-test between the subgroups

**Table 2** Distribution of demographics, clinical characteristics and response to scapular repositioning of participants in subgroups 1 and 2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Subgroup 1  | Subgroup 2  | *p*-value\* | Effect size |
|  | (n = 26) | (n = 32) | Cohen’s d | Cohen’s w |
| Demographics |  |  |  |  |  |
|  Age (years) | 39.3 ± 9.7 | 37.5 ± 10.7 | 0.52 | 0.18 | - |
|  Gender (n, male: female) | 10:16 | 11:21 | 0.75 | - | 0.04 |
|  BMI (kg/m2) | 23.2 ± 3.0 | 22.4 ± 3.0 | 0.31 | 0.27 | - |
| Clinical characteristics  |  |  |  |  |  |
|  Pain duration (months) | 26.6 ± 12.8 | 31.5 ± 11.2 | 0.13 | 0.41 | - |
|  Pain intensity (0 - 10 VAS) | 4.1 ± 0.5 | 4.1 ± 0.5 | 0.80 | 0.00 | - |
|  Neck disability (% NDI) | 31.5 ± 9.7 | 26.9 ± 8.9 | 0.07 | 0.49 | - |
|  Side of neck pain (n, %) |  |  | 0.39 | - | 0.11 |
|  Unilateral  | 7 (26.9) | 12 (37.5) |  |  |  |
|  Bilateral  | 19 (73.1) | 20 (62.5) |  |  |  |
|  Location of neck pain (n, %) |  |  | **<0.001** | - | 0.62 |
|  Upper neck | 6 (23.1) | 1 (3.1) |  |  |  |
|  Lower neck  | 7 (26.9) | 28 (87.5) |  |  |  |
| Whole neck  | 13 (50.0) | 3 (9.4) |  |  |  |
|  Headache (n, %) | 19 (73.1) | 9 (28.1) | **0.01** | - | 0.45 |
| Number of participants responding to scapular repositioning (n, %) |  |  | **<0.001** | - | 0.69 |
|  No response | 3 (11.5) | 26 (81.2) |  |  |  |
|  Positive response | 23 (88.5) | 6 (18.8) |  |  |  |
|  Both pain and cervical range  | 14 (53.8) | 2 (6.3)  |  |  |  |
|  Pain only  | 5 (19.2) | 0 (0.0) |  |  |  |
|  Cervical rotation range only  | 4 (15.4) | 4 (12.5) |  |  |  |

Data are presented as mean ± SD unless otherwise indicated.

\*Independent t-test for continuous variables and Chi-square test for categorical variables.

BMI = body mass index, NDI = pain and disability index, VAS = visual analogue scale