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Diest, Sint-Truiden, June 2014 T.G. and J.P.

Background

This master thesis takes part in a research project, guided by Prof. Sara Van Deun (promotor) and Dra. Liesbet De Baets (copromotor). The emphasis of this project is on scapular kinematics and altered movement patterns in stroke patients, with and without shoulder pain, and healthy controls.

Scapulothoracic motion has an essential part in the functioning of the upper extremity.[1] Not being able to use the upper extremity properly has a detrimental effect on quality of life. Therefore, it is important to be able to measure scapular movement in a valid and reliable manner and to learn about the possible causal mechanisms of post-stroke shoulder pain. However, most of these studies were conducted within the domain of musculoskeletal rehabilitation.

In a previous study a protocol to measure 3D scapular movement patterns was developed. This protocol was proven reliable. However, in order to obtain reliable results, the stroke patients require a relatively good upper extremity function.[2] Furthermore, the protocol has to be executed by an experienced examiner and expensive materials, opto-electronic Vicon cameras, are used. The tests have to be performed in the Laboratory of the Clinical Motion Analysis in the University Hospital Pellenberg. This is time-consuming for patients as well as for the examiner. Therefore, an alternative manner to measure scapular behavior in stroke patients should be developed.

The objective of this is study is to describe the differences found between stroke patients and healthy controls when performing the 3D scapular measurements. Secondly another important goal of this study is to examine the validity of a clinical scapulothoracic joint assessment in stroke patients. This was accomplished by comparing the results of the clinical assessment with the results of the 3D scapular measurements.

Reference list

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Three-dimensional characteristics of the shoulder post-stroke and their relationships to clinical measures.

Opgesteld volgens de richtlijnen van 'Journal of neurologic physical therapy'.

Link auteursrichtlijnen: http://edmgr.ovid.com/jnpt/accounts/ifauth.htm

Abstract

Background: Shoulder complications are common after stroke and influence the upper limb function. Learning about the underlying mechanisms is therefore essential. The aims of this study are to describe the differences found in scapular behavior between stroke patients and healthy controls are described. Secondly, possible relationships between the results of the three-dimensional scapular kinematic analysis and clinical scapular measurements are investigated.

Method: 13 stroke patients and 11 healthy controls were recruited. The movement protocol consisted of two tasks: 45° and 120° unilateral anteflexion of the arm. Markers were placed on the trunk, scapula, humerus and forearm on the hemiplegic side in stroke patients and the dominant side in healthy controls. 3D movements were recorded by 15 Vicon-cameras. Afterwards a clinical examination was executed, measuring scapular lateral rotation by means of inclinometry, scapular distance, acromial distance and pectoralis minor length. SPSS statistics was used for statistical analysis.

Results: Significant differences between both groups were found at the trunk and humerus. Stroke patients showed more extension ($p<0.03$) and heterolateral rotation ($p<0.04$) of the trunk. They also tended to move more in the frontal plane during the lowering phase of the task ($p<0.03$). Moderate to high correlations (0.557 to 0.836) were found between 3D measured scapular rotations measured with 3D analysis and the clinical tests. Stepwise linear regression generated several significant models (R^2 0.336 to 0.824, $p<0.001$ to 0.038) for the prediction of certain 3D scapular measurements.

Conclusion: Stroke patients had a slightly altered movement pattern. There is also evidence that clinical tests can predict the outcome of 3D scapular analysis.

Introduction

As base of the upper extremity, the scapulothoracic joint and glenohumeral joint are of utmost importance considering optimal upper extremity function. To preserve this shoulder function, normal scapulothoracic kinematics are necessary.[1-3] Abnormal scapulothoracic kinematics, also called scapular dyskinesis, seems to be strongly related to shoulder dysfunctions and shoulder pain syndromes.[2-4]

Many stroke patients suffer from upper extremity dysfunctions and shoulder pain. The prevalence of acute upper extremity impairments after stroke vary from 48%[5] up to 77%.[6] Furthermore, up to one third of stroke survivors with arm paresis develops shoulder pain.[7] Several researchers suggest that strokes often have an impact on scapular kinematics. In their studies, scapular and humeral three dimensional movement was compared between stroke patients, with and/or without shoulder pain, and healthy controls. The conclusion was that the stroke patients showed altered scapulothotracic kinematics.[8-10]

However, more studies of high quality on the differences in scapulothoracic kinematics between healthy subjects and stroke survivors are needed. Therefore, the first goal of this study is to compare 3D scapular rotations of stroke survivors to the scapular rotations of healthy age-matched control subjects.

Three-dimensional scapular measures using infrared markers are widely accepted as the gold standard to measure scapular movements. With this device, opto-electronic markers, i.e. infrared light-emitting diodes are registered by multiple cameras.[1,11] In this way detailed data on the 3D rotations of the different shoulder joints can be obtained and the three-dimensional character of shoulder movement in space can be described. However, although the 3D measurement is considered as the gold standard for kinematic shoulder measurement and to identify for example scapular dyskinesis, this technique is time-consuming, expensive and has many requirements with regard to materials and accommodation. This makes it difficult to be used by physicians and physiotherapists at their private practice or at rehabilitation clinics without the three-dimensional measure technology.

As scapular dyskinesis contributes to impaired arm function,[2-4] clinicians should be able to rapidly diagnose this impairment and start an appropriate rehabilitation program as soon as possible. A “clinical scapular protocol” could be beneficial for rapid detection of scapular dyskinesis and proper rehabilitation as it is less expensive, less time invasive and is in need of less material requirements. In this way, physicians and physiotherapists would be able to detect scapular dyskinesis in a more rapid and less expensive way without the use of three-dimensional technology. The second goal of this study is therefore to provide guidelines to develop such a clinical scapular protocol, based on several tests known from the musculoskeletal rehabilitation,[12] and to assess whether the clinical assessment protocol can be used as an alternative for the time-consuming and expensive three-dimensional scapular motion measurement. This will be investigated by assessing the relation between the results of the three-dimensional scapular measurements and the results of the clinical assessment protocol.

Method

Participants

Twenty-four subjects, 13 stroke patients and 11 age and gender matched healthy controls, participated in the study (Table 1). Stroke patients were included if following inclusion criteria were met: 1) they experienced a first, (sub)cortical stroke; 2) reported no shoulder complaints prior to stroke; 3) were two months to one year post stroke; and 4) were able to actively perform 45° of humerothoracic elevation. Subjects were excluded when they suffered any other orthopedic or neurological problem that possibly influenced upper limb function. The healthy controls were recruited via family, friends and colleagues. They were excluded in case of shoulder complaints or current treatment for shoulder pain.

The study received approval of the ethical commission of the University Hospital Leuven. All participants read and signed the informed consent.

Table 1: Group characteristics

Subjects characteristics	Stroke patients	Healthy controls
Number of subjects (men/women)	13 (8/5)	11 (6/5)
Age range (years)	22-68	22-73
BMI (Range)	19.1-26.8	20.2-27.7
Time since stroke in weeks (range)	6-48.3	/
Side of hemiplegia (left/right)	7/6	/
Fugl-Meyer Proximal shoulder/elbow motor section score* - range (mean)	25-36 (31)	/
Fugl-Meyer total upper limb motor section score** - range (mean)	45-65 (56)	/

*: Maximum score =36, **: Maximum score = 66

Measurement protocol

All subjects were evaluated by the same examiner. The measurements were performed in the Laboratory of Clinical Motion Analysis in the University Hospital Pellenberg.

<u>3D assessment protocol</u>

After a brief introduction about the purpose of the study, a total of fourteen markers were placed on the upper body in order to define four segments (trunk, scapula, humerus and wrist). Clusters of three to four markers were secured on tripods and cuffs and placed at the sternum, at the flat part of the acromion and the lateral side of the humerus and wrist (See figure 1)**.** Then a pointer with four linear markers was used to digitize anatomical landmarks during static trials (See figure 2). They were defined within their segmental marker cluster and afterwards used to construct the anatomical coordinate systems and to calculate kinematics of the trunk, scapulothoracic joint, humerothoracic joint and elbow. Three-dimensional rotations for the trunk were flexion/extension, lateral rotation and axial rotation; tilting, medial/lateral rotation, protraction/retraction for the scapulothoracic joint (See appendix A)[13]; plane of elevation, degree of elevation, internal/external rotation for the humerothoracic joint and flexion/extension and pronation/supination for the elbow. This was all done following the ISB guidelines.[13]

Figure 1: Segmental cluster markers

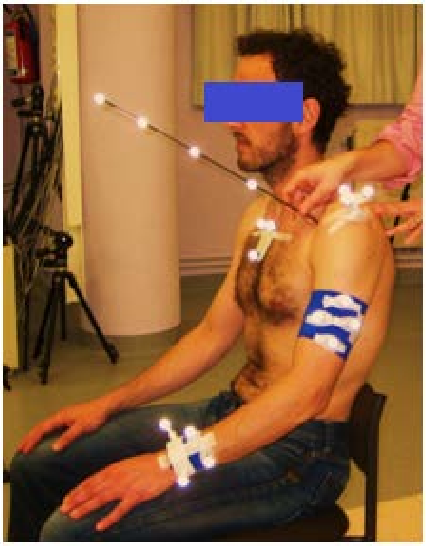

Figure 2: pointer used during static trials

Subjects were seated on a chair with low back support. A pole was placed in front of the subject to provide tactile and visual feedback on how high the arm needed to be raised. The movement protocol consisted of two tasks performed with the hemiplegic side for the stroke patients and the dominant side for the subjects in the control group (See figures 3 and 4). The subjects were asked to perform an active anteflexion of the arm of 45° (task 1) and 120° (task 2). Each task was first explained and the subjects were given time to practice. The examiner sat in front of the subject throughout the measurement demonstrating the exercise and also indicating the speed of movement. Before each task, the subjects were asked to sit upright with the arms hanging relaxed beside the body. Tasks were carried out at a constant speed for all subjects. For the task up to 45°, subjects had two seconds to raise the arm and bring it back to starting position. For the task up to 120°, subjects had two seconds to raise the arm and again two seconds to bring the arm back. Between repetitions, the subjects had respectively two or three seconds of rest. Each individual task consisted of eight repetitions. The 3D movements were captured by the opto-electronic measurement system, Vicon (Oxford Metrics, UK). Fifteen cameras recorded static and dynamic movements of the participants through technical infrared markers placed on the aforementioned bony landmarks.

Figure 3: Anteflexion task (120°) - sideview

Figure 4: Anteflexion task (120°) – dorsal view

Clinical examination

When the movement protocol was completed an extensive clinical examination, consisting of the several clinical scapular measures (pectoralis minor index (PM-index), acromial distance index (AD-index), scapular distance index (SD-index) and measurement of scapular lateral rotation by means of inclinometry at start, 45°, 90° and 135° of passive arm elevation), was performed.[12]

The pectoralis minor muscle length was calculated by measuring the distance between processus coracoideus and the caudal edge of rib four with a tape measure. To calculate the pectoralis minor index, this measured distance was divided by the participant's body length. Also the distance between the angulus acromialis and the third vertebra, was measured as well as the length from the acromion to the medial rim of the scapula. The first mentioned distance was then divided by the latter mentioned length, to calculate the scapular distance. Furthermore, the acromial distance was measured using a sliding caliper. This was the distance between the posterior border of the acromion and the table. It was measured in relaxed position. To obtain the AD-index, this acromial distance was divided by the subject's body length.

Scapular lateral rotation furthermore was measured by using inclinometry. One inclinometer was placed perpendicular to the humeral shaft by one examiner to control humerothoracic elevation while another examiner held the second inclinometer on top of the spina scapulae. Firstly, scapular lateral rotation was measured at start position (0° of humerothoracic elevation). Secondly, scapular lateral rotation was measured at 45°, 90° and 135° of humerothoracic elevation.

Data-analysis

For data-analysis only repetitions 2 to 7 were included. Repetitions 1 and 8 were not used because of the possible presence of start and stop strategies from the subjects.

One repetition consisted of two movement cycles: one from start to highest position (45° or 120°), and one from highest position to start position. Movement start, movement stop and highest position were visually marked. In this way, an elevation phase and a lowering phase were identified. Variables of interest were joint angles at start position, at 45° during the 45° anteflexion task, and joint angles at 45° and 90° of elevation during the 120° anteflexion task. This was done as the acromion marker cluster we used is only valid when humeral elevation does not exceed 100°.[14] Former mentioned joint angles were calculated during the elevation as well as the lowering phase of movement.

Statistical analysis

On the one hand, the goal was to compare differences found between stroke patients and healthy controls. On the other hand, we wanted to assess the relation between the clinical scapular measures and the outcomes of the 3D kinematics of the scapulothoracic joint.

SPSS (IBM SPSS statistics, version 22) was used for statistical analysis. First a normality test (Shapiro-Wilk) was executed. When the alpha-level was more than 0.05, there was a normal distribution. In this case, a one-way ANOVA was used to assess group differences in joint kinematics. On the other hand, a non-parametric test (Mann-Whitney test) was used when there was a non-normal distribution.

The second goal of the study was to examine the relationship between the results found during the 3D scapular measurements and the results of the measures taken afterwards by the examiner during the clinical examination. Only data from the stroke patients was included. First, we calculated Pearson correlations between the 3D measurements of the scapular rotations and the data from the clinical examination. A p-value less than 0.05 represented a significant correlation.

Furthermore, we wanted to know which measurements or combinations of measurements of the clinical examination could predict certain kinematics from the 3D analysis. Stepwise linear regression was applied on the significant correlations. When a 3D measure had significant correlations with one or more measures from the clinical examination, it was entered as a dependent variable. The significantly correlated measures from the clinical examination were entered as independent variables. For every model that was generated, the R^2 and significance were checked. Initially, the alpha-level was set at 0.05. The dependent variables were best explained by models with a rather high R^2 and therefore had a significance less than 0.05. Subsequently, a Bonferoni correction method was used to be even more strict. We divided the alpha level with the number of independent variables which were used to calculate the models of linear regression (kappa). When the significance of the model was less than kappa, the model was assumed to be a good and significant predictor of the dependent variable. Collinearity was also checked. When the tolerance was less than 0.1 and the variance inflation factor (VIF) was more than 10, we assumed that collinearity was present.

Results

Group differences in 3D joint kinematics.

Statistical analysis clearly indicated some significant differences between stroke patients and healthy controls. The results are shown in Tables 2A-2C. For both movement tasks the different 3D measures per joint are shown. Each table shows both the elevation as well as the lowering phase of the movement task. The 3D joint kinematics measured at 45° during the 45° anteflexion task are shown in table 2A. Tables 2B and 2C show the 3D joint kinematics at 45° and at 90°, both measured during the 120° anteflexion task. For both groups the mean values, standard deviations and the corresponding p-values per movement are presented. P-values less than alpha (.05), meaning a significant difference between both groups, are highlighted.

Trunk

Stroke patients showed more extension and heterolateral rotation of the trunk during the 45° anteflexion task (see Table 2A) and during the 120° anteflexion task, measured at 45° (see Table 2B) and 90° (see Table 2C). This was seen both during the elevation and lowering phase of the arm.

Humerothoracic joint

Stroke patients tended to move more in the frontal plane during the lowering phase when performing anteflexion, while control subjects executed the movement in a more sagittal plane.

Scapulothoracic joint

No significant group differences were found at the level of the scapula. Overall, stroke patients moved in a similar way as healthy controls.

Elbow

When performing the 45° anteflexion task, stroke patients showed more flexion, both during the elevation and lowering phase.

Relationship between 3D scapular kinematics and clinical examination

<u>Correlations</u>

The Shapiro-Wilk test showed that both data sets were normally distributed. Pearson-product moment coefficients of correlation were calculated using SPSS. For following three-dimensional scapular kinematic measurements, at least one significant correlation with measurements for the clinical examination was found.

Protraction/retraction:

At start of the movement (AD-index, SD-index, inclinometry 45°; inclinometry 90°)
At 45° of anteflexion during 45° anteflexion task (AD-Index, SD-index)
At 45° of anteflexion during 120° anteflexion task (AD-index, SD-index, inclinometry 90°, inclinometry 135°)
At 90° of anteflexion during 120° anteflexion task (inclinometry 135°)

Lateral/medial rotation:

At start of the movement (inclinometry start, inclinometry 45°)
At 45° of anteflexion during 45° anteflexion task (inclinometry start, inclinmetry 45°)

At 45° of anteflexion during 120° anteflexion task (inclinometry start, inclinometry 45°)
At 90° of anteflexion during 120° anteflexion task (inclinometry start, inclinmetry 45°)

Anterior/posterior tilting:
At 45° of anteflexion during 45° anteflexion task (AD-indext)
At 90° of anteflexion during 120° anteflexion task (humeral elevation at start)

The significant correlations ranged between 0.557 to 0.836. Details of all correlations are shown in Table 3.

<u>Prediction of 3D analysis variables using stepwise linear regression analysis</u>

Stepwise linear regression showed which combinations of clinical measurements could predict the scapular rotations measured during the three-dimensional analysis. The different models for each scapular rotation generated by SPPS are demonstrated in Table 4. The significant models and their independent (Y_n) and dependent (X_n) variables are summarized below.

Protraction/retraction:
Y_1= Start of the movement, $X_{1,2,3}$= SD-Index, AD-Index, inclinometry at 90° elevation.
Y_2= Active 45°-45°, $X_{1,2}$= AD-Index, SD-Index
Y_3= Active 120° - 90°, X= Inclinometry at 135° elevation

Lateral/medial rotation:
Y_1= Start of the movement, X=Inclin-start-laterorot
Y_2= Active 45°-45°, X= Inclin-start-laterorot
Y_3= 120°-90°, X= Inclinometry at 45° elevation

Anterior/posterior tilt:
Y_1= Active 45°-45°, X= AD-Index

Each variable is explained in Table 4. The R square, the F-value and their associated p-value, the intercept, the different b coefficients and their standard error, β-estimate, t-value and the p-value of each model are demonstrated in Table 4. The R-square values and their associated p-values ranged from 0.336 to 0.824 and from 0.038 to <0.001, respectively. All calculated models met the requirements considering collinearity (tolerance>0.1, VIF<10) and the Bonferoni correction method (p-value<kappa).

Table 2A: Group differences in 3D joint kinematics at 45°during 45° anteflexion task: mean value (SD)

Joint	Movement	Stroke patients	Healthy controls	p-value
Elevation phase:				
Trunk	Flexion/extension	-2.8927 (5.32)	1.0451 (4.19)	**0.013**
	Lateral flexion	-0.8365 (1.61)	0.5904 (1.91)	0.060
	Axial rotation	1.9265 (5.53)	3.2995 (7.92)	0.252
Scapulothoracic	Tilting	-2.2727 (7.96)	-3.9466 (7.49)	0.603
	Rotation	-7.0841 (8.16)	-10.2267 (7.85)	0.349
	Pro-/retraction	37.3036 (6.44)	38.4921 (10.47)	0.736
Humerothoracic	Elevation	-44.3710 (2.66)	-44.8426 (0.39)	0.063
	Rotation	-48.3468 (12.64)	-38.0236 (16.05)	0.092
	Elevation plane	64.9709 (4.68)	70.2654 (9.08)	0.303
Elbow	Flexion/extension	25.9539 (7.65)	17.9860 (4.12)	**0.005**
	Pro-/supination	92.1662 (25.34)	79.8072 (15.27)	0.115
Lowering phase:				
Trunk	Flexion/extension	-2.7592 (5.44)	0.9559 (4.19)	**0.030**
	Lateral flexion	-1.0203 (1.77)	0.6378 (1.97)	**0.041**
	Axial rotation	2.5447 (5.57)	3.2678 (7.74)	0.207
Scapulothoracic	Tilting	-2.8777 (8.03)	-4.0829 (7.73)	0.713
	Rotation	-6.7441 (8.70)	-10.2162 (7.93)	0.322
	Pro-/retraction	37.5299 (6.78)	38.6589 (10.54)	0.754
Humerothoracic	Elevation	-43.3433 (3.98)	-44. 8098 (0.39)	0.865
	Rotation	-45.9629 (13.56)	-37. 8786 (14.72)	0.176
	Elevation plane	61.8821 (4.00)	69.5714 (9.19)	**0.012**
Elbow	Flexion/extension	26.2946 (9.36)	18.4603 (4.51)	**0.019**
	Pro-/supination	94.3635 (22.55)	80.9007 (16.57)	0.115

Trunk angles: flexion (+)/extension(-), homolateral lateral flexion (+)/heterolateral lateral flexion (-), internal rotation(+)/external rotation(-)
Scapular angles: posterior tilting(+)/anterior tilting(+), Medial rotation(+)/lateral rotation(-), protraction(+)/retraction(-)
Shoulder angles: flexion (+)/extension(-), adduction(+)/abduction(-), internal rotation(+)/external rotation(-), Elevation plane: 0° = frontal plane & 90° = sagittal plane
Elbow angles: flexion(+)/extension(-), pronation(+)/supination(-)

Table 2B: Group differences in 3D joint kinematics at 45° during 120° anteflexion task: mean value (SD)

Joint	Movement	Stroke patients	Healthy controls	p-value
Elevation phase:				
Trunk	Flexion/extension	-4.1297 (6.37)	1.4214 (3.73)	**0.019**
	Lateral flexion	-1.3149 (2.34)	1.0198 (1.99)	**0.016**
	Axial rotation	1.8308 (6.20)	3.3802 (8.56)	0.361
Scapulothoracic	Tilting	-3. 4490 (7.43)	-3.3122 (6.78)	0.963
	Rotation	-9.6064 (8.62)	-10.7407 (5.48)	0.710
	Pro-/retraction	36.3603 (6.87)	38.5680 (9.59)	0.519
Humerothoracic	Elevation	-44. 8883 (0.56)	-45. 0767 (0.56)	0.422
	Rotation	-43.8672 (11.81)	-33.7732 (18.86)	0.124
	Elevation plane	56.5616 (5.22)	60.6743 (10.44)	0.224
Elbow	Flexion/extension	21.3331 (9.66)	18.6187 (5.71)	0.423
	Pro-/supination	91.8272 (24.88)	83.2654 (17.92)	0.352
Lowering phase:				
Trunk	Flexion/extension	-4.0264 (6.57)	1.3253 (3.88)	**0.027**
	Lateral flexion	-1.6615 (2.51)	0.9830 (1.69)	**0.007**
	Axial rotation	3.0577 (6.07)	3.8996 (8.99)	0.228
Scapulothoracic	Tilting	-5.1729 (8.30)	-3.9214 (6.70)	0.692
	Rotation	-8.9601 (10.51)	-9.0253 (6.42)	0.986
	Pro-/retraction	37.4164 (8.05)	39.9359 (9.41)	0.487
Humerothoracic	Elevation	-44.8645 (0.55)	-45.2179 (0.48)	0.112
	Rotation	-38.4728 (9.68)	-34.7487 (17.34)	0.514
	Elevation plane	51.6810 (6.82)	60.7767 (8.37)	**0.008**
Elbow	Flexion/extension	24.6923 (11.13)	21.5507 (5.98)	0.411
	Pro-/supination	92.6716 (21.81)	81. 7972 (14.95)	0.176

Trunk angles: flexion (+)/extension(-), homolateral lateral flexion (+)/heterolateral lateral flexion (-), internal rotation(+)/external rotation(-)
Scapular angles: posterior tilting(+)/anterior tilting(+), Medial rotation(+)/lateral rotation(-), protraction(+)/retraction(-)
Shoulder angles: flexion (+)/extension(-), adduction(+)/abduction(-), internal rotation(+)/external rotation(-), Elevation plane: 0° = frontal plane & 90° = sagittal plane
Elbow angles: flexion(+)/extension(-), pronation(+)/supination(-)

Table 2C: Group differences in 3D joint kinematics at 90° during 120° anteflexion task: mean value (SD)

Joint	Movement	Stroke patients	Healthy controls	p-value
Elevation phase:				
Trunk	Flexion/extension	-4.3023 (7.34)	1.5086 (3.79)	**0.027**
	Lateral flexion	-2.3065 (4.19)	2.0213 (1.78)	**0.004**
	Axial rotation	2.5169 (6.34)	3.9007 (8.97)	0.733
Scapulothoracic	Tilting	0.7693 (9.85)	2.8530 (8.64)	0.591
	Rotation	-32.1658 (12.30)	-30.8177 (7.62)	0.756
	Pro-/retraction	46.5340 (10.95)	45.2782 (11.80)	0.790
Humerothoracic	Elevation	-90.0370 (0.26)	-90.1534 (0.27)	0.297
	Rotation	-47.5399 (11.96)	-42.5803 (13.94)	0.358
	Elevation plane	69.3279 (6.34)	72.5188 (7.75)	0.279
Elbow	Flexion/extension	22.5798 (7.47)	21.8182 (5.77)	0.786
	Pro-/supination	85.3148 (23.33)	75.1710 (16.50)	0.240
Lowering phase:				
Trunk	Flexion/extension	-4.4870 (7.72)	1.5500 (4.11)	**0.030**
	Lateral flexion	-3.1229 (4.57)	2.2607 (2.05)	**0.002**
	Axial rotation	3.0329 (6.35)	4.2477 (9.02)	0.608
Scapulothoracic	Tilting	0.5636 (10.60)	2.5443 (9.84)	0.642
	Rotation	-33.7058 (13.14)	-31.6923 (8.90)	0.671
	Pro-/retraction	45.3591 (10.71)	44.8046 (13.86)	0.913
Humerothoracic	Elevation	-90.0730 (0.49)	-89.9350 (0.36)	0.450
	Rotation	-44.5937 (10.72)	-41.0779 (15.20)	0.514
	Elevation plane	65.0373 (5.72)	71.4553 (7.81)	**0.030**
Elbow	Flexion/extension	25.1085 (9.47)	22.8762 (6.09)	0.509
	Pro-/supination	84.6816 (22.22)	74.5769 (15.83)	0.221

Trunk angles: flexion (+)/extension(-), homolateral lateral flexion (+)/heterolateral lateral flexion (-), internal rotation(+)/external rotation(-)
Scapular angles: posterior tilting(+)/anterior tilting(+), Medial rotation(+)/lateral rotation(-), protraction(+)/retraction(-)
Shoulder angles: flexion (+)/extension(-), adduction(+)/abduction(-), internal rotation(+)/external rotation(-), Elevation plane: 0° = frontal plane & 90° = sagittal plane
Elbow angles: flexion(+)/extension(-), pronation(+)/supination(-)

Table 3: Correlations between 3D scapular rotations and clinical examination measures

	3D Scapular rotation	AD-Index	PM-Index	SD-Index	Inclinometry 45°	Inclinometry 90°	Inclinometry 135°	Inclinometry start
Pro/retraction	Start of movement							
	Pearson correlation	**0.728****	0.225	**0.802****	**0.562***	**0.678***	0.494	0.295
	Significance	0.005	0.461	0.001	0.046	0.011	0.086	0.327
	N	13	13	13	13	13	13	13
	Antefl 45° - 45°							
	Pearson correlation	**0.662***	0.283	**0.635***	0.545	0.550	0.467	0.355
	Significance	0.014	0.349	0.020	0.054	0.052	0.108	0.234
	N	13	13	13	13	13	13	13
	Antefl 120° - 45°							
	Pearson correlation	**0.736****	0.190	**0.656***	0.614	**0.720****	**0.571***	0.353
	Significance	0.004	0.535	0.015	0.025	0.006	0.042	0.236
	N	13	13	13	13	13	13	13
	Antefl 120° - 90°							
	Pearson correlation	0.521	0.145	0.380	0.439	0.535	**0.580***	0.224
	Significance	0.068	0.635	0.200	0.133	0.060	0.038	0.463
	N	13	13	13	13	13	13	13
Medial/lateral rotation	Start of movement							
	Pearson correlation	0.107	0.369	0.070	**0.720****	0.315	0.407	**0.836****
	Significance	0.728	0.214	0.821	0.006	0.294	0.167	0.000
	N	13	13	13	13	13	13	13
	Antefl 45° - 45°							
	Pearson correlation	0.110	0.223	0.173	**0.699****	0.355	0.403	**0.796****
	Significance	0.729	0.465	0.571	0.008	0.233	0.172	0.001
	N	13	13	13	13	13	13	13
	Antefl 120° - 45°							
	Pearson correlation	0.207	0.004	0.127	**0.690****	0.416	0.404	**0.658***
	Significance	0.498	0.989	0.680	0.009	0.157	0.171	0.015
	N	13	13	13	13	13	13	13
	Antefl 120° - 90°							
	Pearson correlation	0.202	-0.162	-0.020	**0.620***	0.322	0.436	**0.557***
	Significance	0.509	0.597	0.949	0.024	0.284	0.137	0.048
	N	13	13	13	13	13	13	13

Table 3: Continued

	3D Scapular rotation	AD-Index	PM-Index	SD-Index	Inclinometry 45°	Inclinometry 90°	Inclinometry 135°	Inclinometry start
Posterior/anterior Tilting	Start of movement							
	Pearson correlation	0.528	-0.254	0.046	-0.190	-0.030	-0.091	-0.299
	Significance	0.063	0.403	0.881	0.533	0.923	0.768	0.321
	N	13	13	13	13	13	13	13
	Antefl 45° - 45°							
	Pearson correlation	**0.593***	-0.084	0.209	0.035	-0.067	-0.066	-0.026
	Significance	0.033	0.784	0.494	0.909	0.828	0.829	0.932
	N	13	13	13	13	13	13	13
	Antefl 120° - 45°							
	Pearson correlation	0.496	-0.206	0.134	-0.107	-0.089	-0.161	-0.207
	Significance	0.084	0.499	0.662	0.729	0.772	0.599	0.497
	N	13	13	13	13	13	13	13
	Antefl 120° - 90°							
	Pearson correlation	0.420	-0.154	0.191	0.088	0.070	-0.244	0.100
	Significance	153	0.615	0.532	0.776	0.821	0.421	0.745
	N	13	13	13	13	13	13	13

Start of movement: Scapular rotations measured at the start of the movement task before any movement has occurred
Antefl 45° - 45°: Scapular rotations measured during 45° anteflexion of the shoulder at 45° anteflexion
Antefl 120° - 45°:Scapular rotations measured during 120° anteflexion of the shoulder at 45° anteflexion.
Antefl 120° - 90°: Scapular rotations measured during 120° anteflexion of the shoulder at 90° anteflexion
N: number of subjects measured
* **Significance is significant at the 0.05 level**
** **Significance is significant at the 0.01 level**

Table 4: Multiple Linear Regression models with stepwise selection

	Dependent variable	#	Retained independent variables	R^2	F	p–value¹	Intercept	Coefficient b	SE	β	t	p–value²
Pro/retr	Start	1	SD_Index	0.644	19.898	0.001	-20.463	31.635	7.092	0.802	4.461	0.001
		2	SD_Index AD_Index	0.745	18.555	<0.001	-21.500	23.064 3.609	6.621 1.387	0.585 0.437	3.484 2.602	0.006 0.026
		3	SD_Index AD_index Inclinometry 90°	0.824	19.745	<0.001	-7.425	19.105 2.944 0.268	5.775 1.187 0.115	0.485 0.357 0.324	3.320 2.481 2.342	0.009 0.035 0.044
	Active 45°-45°	4	AD_Index	0.438	8.585	0.014	17.233	5.012	1.711	0.662	2.930	0.014
		5	AD_Index SD_Index	0.562	6.427	0.016	0.389	3.483 14.675	1.825 8.715	0.460 0.406	1.908 1.684	0.085 0.123
	Active 120° - 90°	6	Inclinometry 135°	0.336	5.570	0.038	72.753	0.654	0.277	0.580	2.360	0.038
Med/lat rot	Start	7	Inclin_start_laterorot	0.699	25.516	<0.001	-2.386	1.009	0.200	0.836	5.051	<0.001
	Active 45° - 45°	8	Inclin_start_laterorot	0.634	19.055	0.001	-8.782	0.960	0.220	0.796	4.365	0.001
	Active 120° - 90°	9	Inclinometry 45°	0.475	6.871	0.009	-28.673	1.227	0.468	0.620	2.621	0.024
Ant/post tilt	Active 45° - 45°	10	AD_Index	0.351	5.958	0.033	-24.290	5.504	2.255	0.593	2.441	0.033

#: Model number, **R^2**: R square, **F**: F-value, **p-value¹**: significance level associated with the corresponding F-value, **SE**: Standard Error, **β**: estimate, **t**: t-value, **p-value²**: Significance level of the equation coefficient, **Pro/retr**: Scapular protraction/retraction angles, **Med/lat rot**: Scapular medial rotation/lateral rotation angles, **Ant/post tilt**: Scapular anterior/posterior tilting rotations, **Start**: 3D rotations measured at the start of the anteflexion task, **Active 45°-45°**: 3D rotations measured at 45° during the 45° anteflexion task, **Active 120°-90°**: 3D rotations measured at 90° during the 120° anteflexion task, **SD_Index**: (Scapular Distance)/(Subject height), **AD_Index**: (Acromial Distance)/(Subject height), **Inclin_start_laterorot**: Scapular lateral rotation measured with an inclinometer at the start of the elevation task, **Inclin_start_hum_elev**: Humeral elevation measured with an inclinometer at the start of the elevation task, **Inclinometry 45°/90°/135°**: scapular lateral rotation measured with an inclinometer at 45°/90°/135° of elevation.

Discussion

The difference in joint kinematics, at the scapulothoracic joint in particular, between stroke survivors and healthy subjects was one of our main interests while conducting this study. Certain studies have already managed to demonstrate the presence of an altered scapulohumeral rhythm after stroke.[10] Therefore, it seemed reasonable to assume that a difference in scapular kinematics between stroke survivors and healthy subjects could be demonstrated.

However, in this study no significant differences between both groups concerning the kinematics of the scapulothoracic joint were found. This is in contradiction with the findings of other studies.[8-10] Here an altered scapulohumeral rhythm was found in stroke survivors. We thought of several possible reasons for the absence of a significant difference in scapulothoracic joint kinematics between stroke survivors and healthy controls: For instance, the small sample size (n=24, stroke=13, control=11) could be partly responsible. Secondly, our stroke subjects seemed to have only mild upper limb dysfunctions. This assumption is supported by their Brunnstrom Fugl Meyer score (See Table 1). The mean scores for the Proximal shoulder/elbow and total upper extremity parts were 31 (maximum score: 36) and 56 (maximum score: 66), respectively. Third, we only analyzed anteflexion tasks. Several studies also used abduction/elevation tasks for the evaluation of scapular kinematics.[8-10,15] However, research proved abduction tasks to be less reliably measurable in stroke patients.[16] Finally, abnormal scapular kinematics are also seen in painfree persons without stroke.[3] Therefore, it is possible that these altered kinematics were present in certain subjects of the control group. This could have influenced our results.

Significant differences between groups were found at the trunk, humerothoracic and elbow level. It is possible that the compensations at the trunk are responsible for the absence of significant differences between both groups at the scapulothoracic joint. Furthermore, trunk extension and heterolateral flexion could possibly explain why the anteflexion task is executed in a more frontal plane in the stroke group. These movements changed the rotation point of the humerus in space, while the location of the pole which serves as end point of the movement task did not change.

The stepwise linear regression showed that several variables obtained from the clinical examination could predict certain measures of the 3D analysis. The following statements apply to stroke survivors only. Based on the results of the current study, we suggest that the clinical measurements which could be included into a clinical examination to evaluate scapular kinematics are the SD-index, the AD-index and inclinometry at the start, at 45°, at 90° and at 135° of humeral elevation. The models for predicting the scapular protraction/retraction, medial/lateral rotation and anterior/posterior tiling, at the start and during several anteflexion tasks, can be composed of the clinical measurements mentioned above (for details see Table 4). When a model contains more than one clinical measure, it is important to consider the time it takes and the experience needed to execute the measures. An example is given for predicting the protraction/retraction at the start of an anteflexion task. When inclinometry at 90° of humeral elevation is measured next to the SD-index and the AD-index, the R^2 value equals 0.824. Without the inclinometry 90°, the R^2 is still high (0.745). Furthermore, inclinometry has to be executed by two experienced examiners. Therefore, using the model only containing the SD-index and AD-index can be justified. Although the R^2 value for this model is slightly less, it can be performed quickly and only takes one examiner. The R^2 values of the generated models range from 0.336 to 0.824. This means that certain models are better suited to predict certain 3D scapular kinematics than others. Now that we know the value of combinations of clinical tests to predict scapular rotations, we are able to investigate scapular behavior in larger samples, outside of the laboratory.

In order to interpret the results of the clinical measurements described in the present study, normative data concerning these measurements are of utmost importance. Therefore, we recommend that more qualitative studies should be performed to gather normative data. Without doubt it is essential to gather normative data concerning healthy subjects and stroke survivors, both with and without shoulder pain. This would make it possible for home practitioners to make assumptions about the scapular kinematics of their patients, based on the results of these rather simple clinical measurements. The different models and their R^2 values (Table 4) along with the amount of time available to examine their patients can help the practitioner to choose which measurements to perform.

This study, provides evidence for using certain clinical examinations of the clinical assessment protocol to evaluate the kinematics of the scapulothoracic joint of stroke survivors.[13] Nevertheless, there is need for more qualitative studies with large sample sizes to validate these results and confirm the proposed statements.

Conclusion

Significant differences between stroke survivors and healthy controls were found at the trunk, humerothoracic and elbow level, whereas at the scapulothoracic joint no significant differences were found. The reason probably lies within the fact that we only included high functioning stroke patients.

Furthermore, this study has delivered some evidence for using the SD-Index, AD-index and inclinometry of the scapula at various degrees of humeral elevation (0°, 45°, 90° and 135°) to predict three-dimensional scapular movement data. Nevertheless, there is need for more qualitative studies with large sample sizes to determine the exact protocol which should be used, and for normative data on these clinical tests to properly interpret results in stroke patients.

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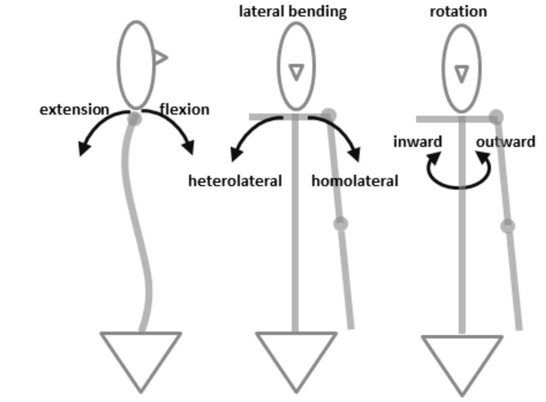
Appendix A

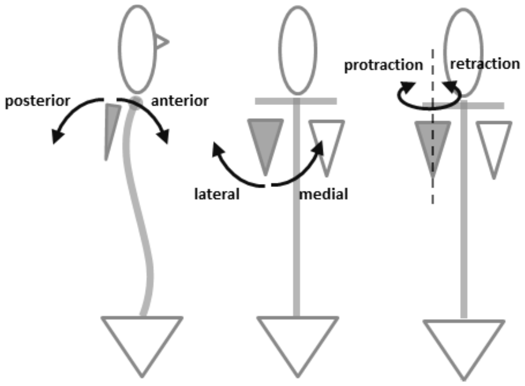
4. Data interpretation

4.1 Kinematics



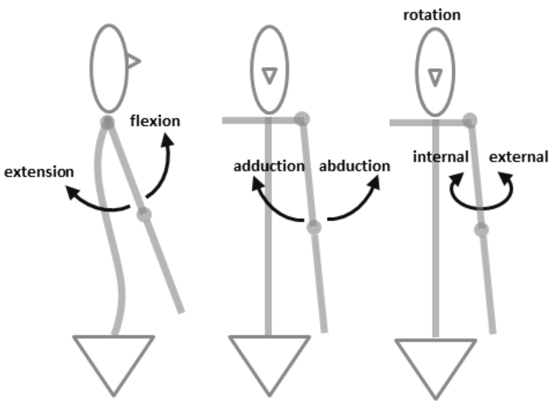
Trunk angles

Flexion (+)	Extension (-)
Homolateral lateral Fl (+)	Heterolateral lateral Fl (-)
Internal rotation (+)	External rotation (-)



Scapular angles

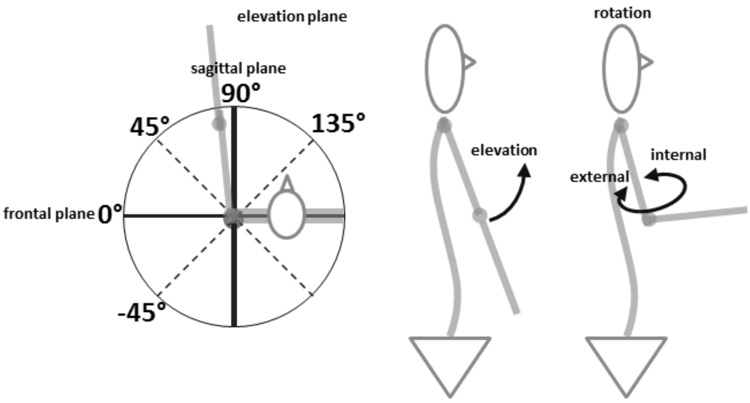
Posterior tilting (+)	Anterior tilting (-)
Medial rotation (+)	Lateral rotation (-)
Protraction (+)	Retraction (-)



Shoulder angles

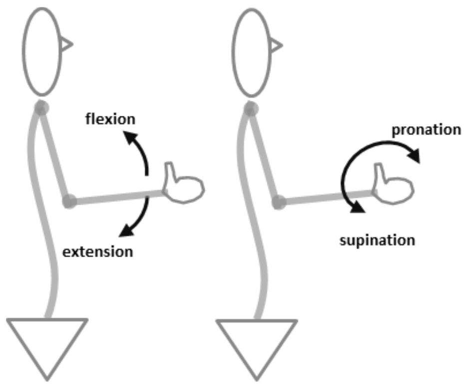
Standard decomposition

Flexion (+)	Extension (-)
Adduction (+)	Abduction (-)
Internal rotation (+)	External rotation (-)



Globe decomposition

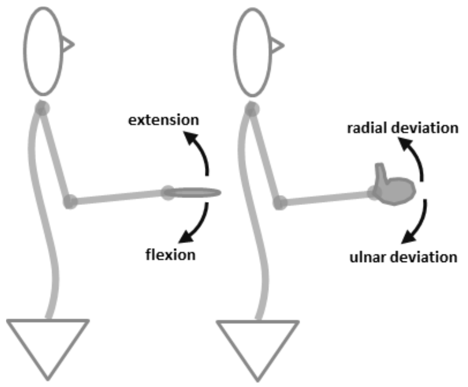
Plane of elevation	0° frontal	90° sagittal
Elevation (+)		
Internal rotation (+)	External rotation (-)	



Elbow angles

Flexion (+) Extension (-)

Pronation (+) Supination (-)



Wrist angles

Flexion (+) Extension (-)

Ulnar deviation (+) Radial deviation (-)

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Three-dimensional characteristics of the shoulder post-stroke and their relationships to clinical measures

Richting: **master in de revalidatiewetenschappen en de kinesitherapie-revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen**
Jaar: **2014**

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