Rotator cuff degeneration in the rheumatoid shoulder : 'the issue is soft tissue'

Sande, M.A.J. van de

Chapter 3.3

Comparison between tripod and skin-fixed recording of scapular motion.

C.G.M. Meskers, M.A.J. van de Sande, J.H. de Groot.
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Summary

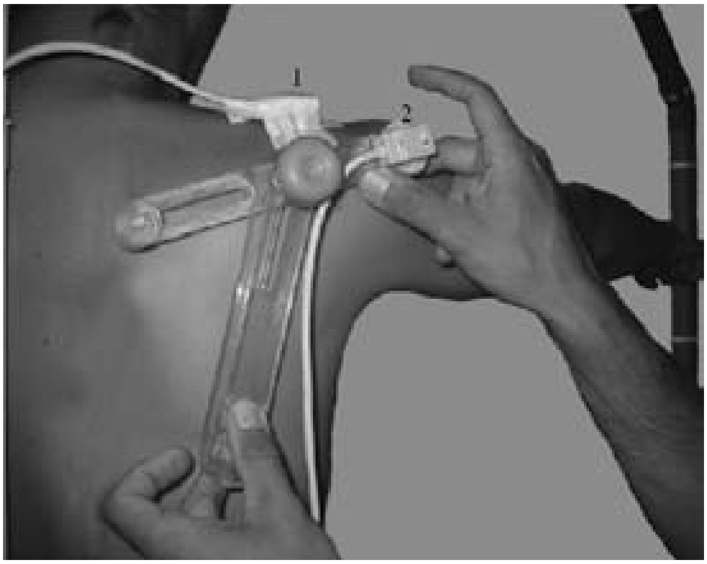
Non-invasive dynamical measurements of 3D scapular motion can be performed easily by attachment of a 6 DOF electromagnetic receiver onto the skin above the acromion. To quantify the introduction of possible errors due to skin displacement, we assessed 3D scapular positions on n=8 subjects by both tripod and skin-fixed method. Error analysis included the variables method (tripod, skin-fixed simultaneously with tripod, separate skin-fixed at 0 and 0.25 Hz of elevation speed), plane of elevation (0° and 90°) and observation (receiver replacement: n=3). Inter-individual 'group' differences depended on elevation plane and showed an average underestimation of scapular rotation of 6.5° (worst case 13°) using the skin-fixed method. Only the group RMSE, not the individual RMSE, could be successfully lowered using linear regression (to about 21). Inter-trial reliability (RMSE<3.24°, ICC>0.94) and RMSE between 0 and 0.25 Hz recordings (about 2.5°) were satisfactory. Intra-observer RMSE after replacement of the skin-fixed receiver was 5°. The skin-fixed method is suitable for dynamic recordings of scapular rotations; however, measurements are precise only when the acromion receiver is not replaced. Combined with a relatively low accuracy, we conclude that the skin-fixed method should be used only in combination with tripod 'calibration'.

Introduction

For non-invasive measurements of scapular kinematics, the palpation method proved to be clinical applicable.[149-151] Johnson et al. proposed the use of an active 6 DOF electromagnetic receiver mounted on a tripod, to be placed manually over the scapular bony landmarks.[152] Accuracy of this method proved to be sufficient for clinical measurements.[153] Disadvantages of this method are the impossibility to measure dynamically and the introduction of inter-observer variability. By attaching an electromagnetic receiver directly onto the skin above the acromion[154-157] these problems would theoretically be circumvented; however, new errors due to skin displacement are quite likely introduced. To properly evaluate measurements based on this method, the magnitude of these errors should be known. In this study, we:

1. Compared the 'standard' tripod measurements toacromion receiver measurements by an internationally standardized measurement protocol[158];
2. Assessed the intra-observer (after replacement of the receiver) and the inter-trial variability;
3. Compared statically recorded arm motions to recordings at moderate velocity.

Figure 1. Experimental set-up: measurements of 3D scapular rotations performed by a 6 DOF active receiver glued to the acromion (1) are validated by measurements using a manually positioned tripod with a receiver attached to it (2).



Methods

In all, n=8 healthy subjects (4 male, 4 female, age 29±10 yr) were measured using an electromagnetic tracking device (Flock of Birds, FoB, Ascension Technology, Burlington VT, USA) with an extended range transmitter. A field calibration was performed.[159] Subjects were in a seated position with two adjustable semicircular pipes placed on both sides to assist in keeping the proper elevation angle and plane. Receivers were attached to sternum, strapped to upper arm and wrist and mounted on both a tripod and a stylus of about 0.05m length, respectively. A 6th receiver was mounted on the flat part of the acromion, in the most latero-caudal corner, just above the angulus acromialis (Figure 1). The receiver was glued to the skin using doublesided tape; two crossed strips of elastic tape were applied as extra fixation. Initial measurements were performed during which 3D positions of bony landmarks (Table 1) were assessed in the local co-ordinate system of the bonefixed receivers by using the stylus. After fitting the adjustable tripod on the individual scapula, 3D positions of its end points were obtained.[153] Measurements were performed on the right arm starting from an initial position with the arms vertically along the body. Symmetrical active elevations were then performed in the frontal (= abduction, 0°) and sagittal plane (= anteflexion, 90°), respectively. The elevation trajectory was divided in 11 intervals of about 15° as marked on the guiding pipes. The subject was to hold still between each interval, allowing the observer to position the tripod onto the scapula. Measurements were performed by three observers. Each observer had to re-adjust the dimensions of the tripod to fit the scapula before starting his measurement series/ session. Four series of measurements were performed:

(1) Scapular position recordings by tripod and skinfixed acromion receiver simultaneously (n=3 observers).
(2) n=3 repetitions of 151 intermittent (static) elevations, using only the skin-fixed acromion receiver, excluding effects of skin manipulation through palpation (n=1 observer).
(3) n=3 continuous elevation motions (0.25 Hz cyclic ab-adduction) (n=1 observer).
(4) n=3 repetitions of measurements after replacement of the acromion receiver (n=1 observer).

Table 1. *Bony landmarks, local co-ordinate systems and decomposition/rotation order per bone as used in this study* [158]

Bone/bony landmarks	Co-ordinate systems	Rotation order
Thorax Processus xyphoideus(PX)	Origin: IJ	
Incisura jugularis(IJ)	y-axis: Line connecting midpoint PX-T8 and midpoint IJ-C7 pointing upward	$^{G}Z_{T}$
Processus spinosi C7	z-axis: Line perpendicular to plane IJ-C7 and midpoint PX-T8 pointing to the right	$^{G}X_{T}'$
Processus spinosi T8	x-axis: Perpendicular to y- and z-axis pointing forwards	$^{G}Y_{T}''$
Scapula	Origin: AA	
Angulus acromialis (AA)	z-axis: Line connecting TS and AA pointing to AA	$^{T}Y_{S}$
Trigonum spinae (TS)	x-axis: Perpendicular to the plane AA–TS–AI, pointing forward	$^{T}X_{S}'$
Angulus inferior (AI)	y-axis: Perpendicular to x- and z-axis pointing upward	$^{T}Z_{S}'$
Humerus	Origin: GHa	
Epicondylus lateralis (EL)	y -axis: Line connecting midpoint EL-EM and GH pointing upward	$^{T}Y_{H}$
Epicondylus medialis (EM)	x-axis: Perpendicular to plane EL-EM–GH pointing forward	$^{T}X_{H}'$
Gleno humeral joint rotation center[a] (GH)	z-axis: Perpendicular to y- and z-axis pointing to the right	$^{T}Y_{H}''$

[a] Not a true bony landmark but estimated from regression equations (Meskers et al., 1997).

The initial measurements allowed for calculation of the 3D positions of three non-collinear bony landmarks for each bone in the global co-ordinate system. Definitions of the bone-fixed local co-ordinate systems and subsequent decomposition were according to Wu et al. (Table 1).[158] The arm elevation task, though standardized, resulted in variable humerus positions and forthcoming variance on scapular orientations. To eliminate this source of variance, data-interpolation was performed by using p-splines. (Eilers and Marx, 1996). Re-sampled scapular rotations (at discrete humerus elevation angles: 30°, 50°, 70°, 90°, 110° and 130°) were used for statistical testing.

Concurrent validity of the scapular orientation obtained by the skin-fixed towards the tripod method was assessed by a repeated measurement ANOVA (SPSS 11.5). Independent variables were *method* ((1) tripod recordings, calculated as the mean of n=3 observers, (2) skin-fixed recordings simultaneously with the tripod recordings, (3) separate statical skinfixed recordings (0 Hz) and (4) dynamical skinfixed recordings (0.25 Hz)), *plane of elevation* (frontal and sagittal), *observation* (replacement of the acromion receiver) and elevation *angles* (30°, 50°, 70°, 90°, 110° and 130°). *Scapular rotations* (${}^{T}Y_{S}$, ${}^{T}X_{S}$ and ${}^{T}Z_{S}$) measured by tripod were treated as dependent outcome variables. Also, inter-observer variability and differences between recordings at 0 and 0.25 Hz were assessed. RMSEs and intra-class correlations were calculated separately to estimate the inter-trial variability. Stepwise linear regression (SPSS 11.5) was applied to try to estimate a transfer function between tripod and skin-fixed recordings. Potential regressors for the outcome parameters [${}^{T}Y_{S}$, ${}^{T}X_{S}$, ${}^{T}Z_{S}$], averaged for n=3 observers were [${}^{T}Y_{S\_acr}$, ${}^{T}X_{S\_acr}$, ${}^{T}Z_{S\_acr}$], humeral elevation angle (-${}^{T}X_{H}$: [30°, 50°, 70°, 90°, 110° and 130°]) plane of elevation (${}^{T}Y_{H}$), and axial rotation (${}^{T}Y_{H}''$). Only factors significantly contributing to the model were included.

Table 2. Results of a repeated measurements ANOVA with independent variables ***plane*** *(elevation in frontal and sagittal plane),* ***method*** *(tripod, skin-fixed simultaneously with tripod, skin-fixed at velocity oHz and skin-fixed at velocity 0.25 Hz),* ***observer*** *(n=3) and* ***angle*** *(n=6)*

	Plane	Method	Angle	Plane x method	Plane x angle	Observe x angle	Method x angle x angle	Plane x method x angle	Method observe
${}^{T}Y_{S}$	**	**			**		**		
$-{}^{T}X_{S}$	**	**	**	**	**	**	**	**	**
${}^{T}Z_{S}$		*	**		*		*	**	

Only significant variables and interactions are presented with respect to the dependent variables ${}^{T}Y_{S}$ (pro/retraction), $-{}^{T}X_{S}$ (latero rotation) and ${}^{T}Z_{S}$ (spinal tilt) (*p<0;05,** p<0;01).

Figure 2. *Top row: scapular rotations of the mean tripod recordings (mean of n=3 observers and n=8 subjects) and inter-subject standard deviation (error-bar). Bottom row: mean differences between simultaneous skin-fixed and tripod measurements (open circles), between separate skin-fixed and tripod measurements (asterisks) and between 0 and 0.25 Hz recordings (squares).*

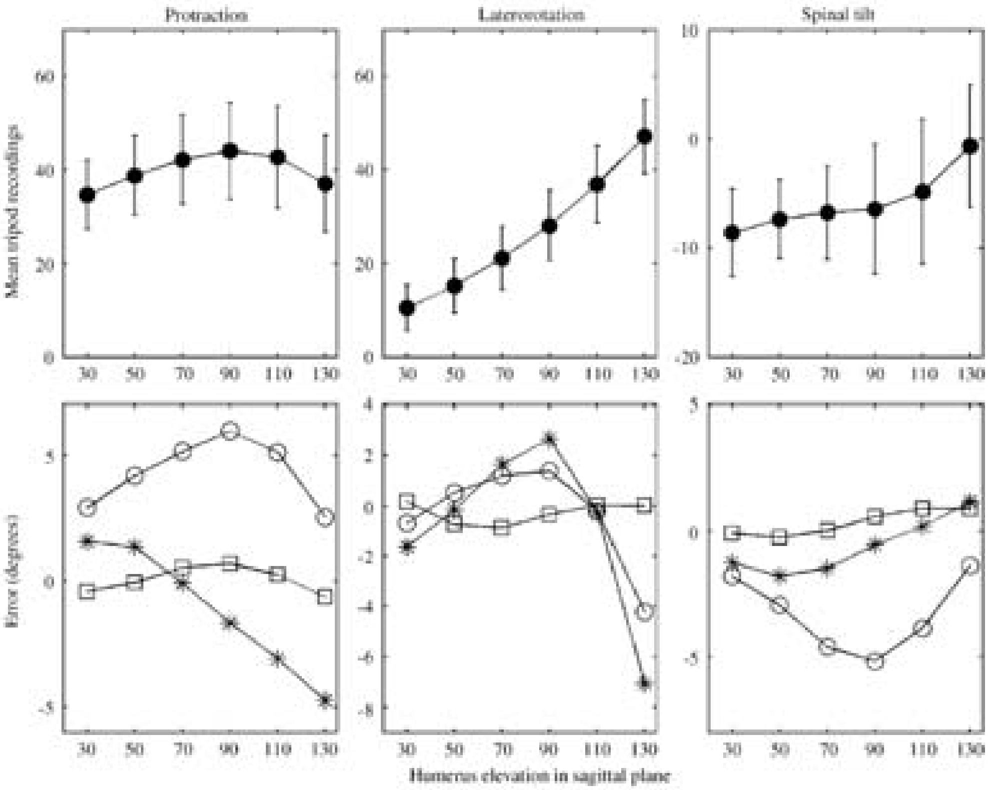
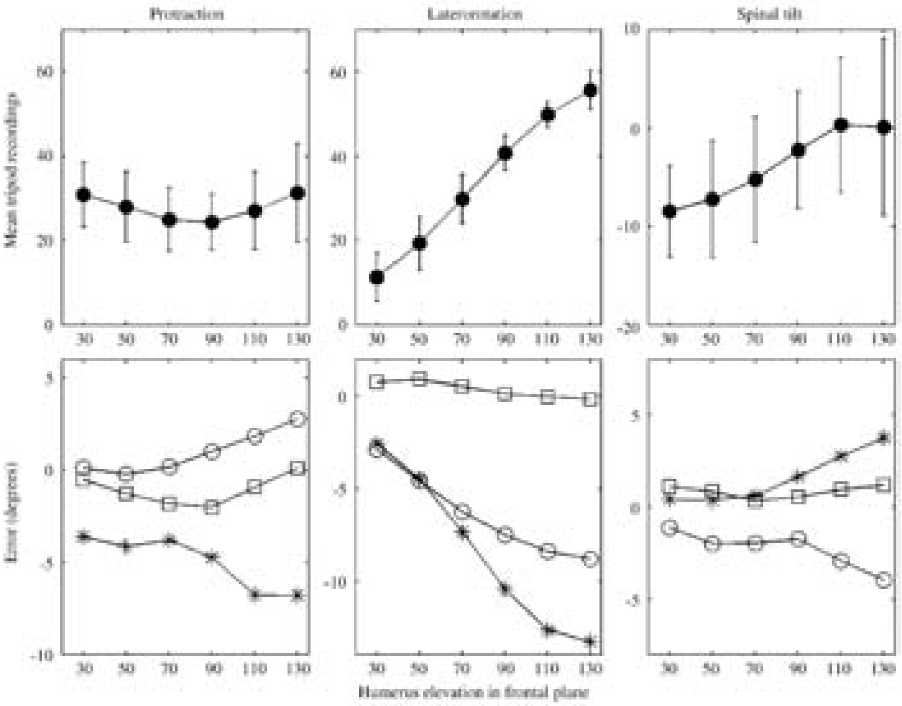


Table 3. *Results (RMSE in degrees, model determinants and values) of a linear regression procedure to fit the error between scapular rotations as measured by the skin-fixed and the rotations measured by the tripod method ($-^{T}X_{S\_acr}$: lateral rotation as measured by skin-fixes method; $^{T}Y_H$: humerus elevation plane).*

	RMSE	RMSE corrected	Model constant	$^{-T}X_{S\_acr}$	$^{T}Y_H$
$^{T}Y_S$	3.88 (9.74)	0.92 (7.76)	15.7	0.48	0.10
$^{-T}X_S$	6.47 (8.87)	2.00 (6.77)	1.87	1.41	-120
$^{T}Z_S$	1.00 (6.13)	0.45 (4.55)	-0.70	0.87	0.015

In brackets are the results of the application of the model to data of individual subjects.

Figure 3. *As Figure 2, only for elevation in the frontal plane.*



Results and discussion

Actual bone motions are generally underestimated using skin-fixed recording methods, which appears to be true for the scapula as well. During elevation in the sagittal plane (^TY_H = 90°), the differences between the skin-fixed and the tripod recordings are maximally 7°(Figure 2), while skin-fixed recordings underestimate scapular latero-rotation by maximally 13° during elevation in the frontal plane (Figure 3). There was a considerable difference between scapular orientation measurements either with or without simultaneous tripod recordings (Figs. 2 and 3). Apparently, the position of the skin-fixed receiver relative to the acromion is very sensitive to manipulation, something that has to be taken into account when calibrating skin-fixed recordings. Karduna et al. compared skin-fixed recordings to recordings from a bone sensor attached to k-wires inserted transcutaneously into the scapular bone.[160] In contrast to our observations, skinfixed rotations were reported to be larger than the actual bony rotations. Possibly, either the transcutaneous bone-sensor fixations and/or the skin onto which the second scapular sensor was fixed were susceptible to motion interactions. In Table 2. the results of repeated measurements ANOVA are presented. For the scapular pro/retraction (^TY_S), humerus *plane* of elevation (^TY_H) is a significant co-variable, indicating a difference in scapular rotation between elevation in frontal and sagittal plane. The variable *method* significantly differed between tripod and simultaneous skin-fixed measurements on one hand and separate skin-fixed measurements during 0 and 0.25 Hz elevation velocity on the other. The significant *method*–elevation *angle* interaction with scapular orientation illustrated that the different means of recording became more pronounced at the higher elevation angles. For scapular latero-rotation (-$^{T}X_{S}$), a similar effect was found, with an obvious significant *angle* effect and a significant *observer–angle* interaction. For *scapular* spinal tilt ($^{T}Z_{S}$), *method* and *angle* were significant while *plane* was not. Application of regression models resulted in a decreased RMSE between skin-fixed and tripod recording for the pooled 'group' data. On individual basis, it was not possible to lower the error by means of a single general model (Table 3), which indicates the presence of unpredictable inter-individual or inter-measure determinants like variability in skin to bone displacement and soft tissue deformity by *m. Deltoideus* contraction. Skin-fixed scapular recording allows the subjects to perform natural motions, reduces the recording time and motor noise and is more comfortable. No significant additional variability is introduced by dynamical recordings with a RMSE comparable to the inter-trial variability (2.38° vs. 2.33°) and high ICCs (mean 0.97). Recording speed using electromagnetic tracking devices is limited as motion artefacts are introduced due to the sequential sampling of the receivers and the relatively low sample frequency (inversely proportional to the number of receivers, maximally 133 Hz), resulting in pseudo translations and rotations when synchronicity is presumed. Also the mass of the sensors may result in inertial translations and rotations of the receivers. The low inter-trial RMSEs indicate that measurements by skin-fixed method are highly reproducible. An RMSE of about 2° is close to the estimated error evolving from motor noise during statical measurements.[151;153] Remarkably, the intra-observer RMSE of the skinfixed method is about equal to the inter-observer RMSE of the tripod method (5.0° vs. 4.7°). Tripod measurements require manipulation with a locator, with potential differences between observers, while skin-fixed recordings require only fixation of the receiver on the acromion at one stage of the measurements and palpation of initial bony landmarks. Apparently, skinfixed recordings are sensitive to positioning on the acromion, a variable that is difficult to control. Together with the susceptibility of the acromion receiver position to manipulation and the impossibility to lower the intraindividual error by (linear) regression, it is concluded that the skin-fixed method for scapular recordings is precise only when recordings are compared without replacement of the receiver; when this is the case, e.g. when comparing recordings after a time interval, the precision of skin-fixed method is lowered considerably. This together with the problems of accuracy especially at the higher elevation angles makes that the skin-fixed recordings of scapular position should be calibrated using a tripod during each recording session. Note that this calibration cannot be performed simultaneously and has to be performed prior or after the actual recording session.