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Accuracy of measuring scapular position and motion with a novel motion capture system

Matteo Mantovani, MSc, MBA[a,*], Aaron Sciascia, PhD, ATC, PES, SMTC, FNAP[b], Alessandro Varini, MSc[a], Marco Muraccini, PhD[a], Fabrizio Nardini, PhD[a], Pietro Tonino, MD[c], Benjamin W. Kibler, MD[d]

[a] *NCS Lab Srl, Medical Device Research Lab, Carpi (Modena), Italy*
[b] *Institute of Clinical Outcomes and Research, Lexington Clinic, Lexington, KY, USA*
[c] *Department of Orthopaedic Surgery and Rehabilitation, Stritch School of Medicine, Loyola University Chicago, Maywood, IL, USA*
[d] *Shoulder Center of Kentucky, Lexington Clinic, Lexington, KY, USA*

A R T I C L E I N F O

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Level of evidence: Level II; Diagnostic Study

Background: Scapula kinematics is recognized to be a crucial variable in shoulder dysfunction. Nevertheless, quantitative scapula tracking and measurement are not part of the current clinical evaluation. The main concern is measurement accuracy.

Methods: To assess the accuracy of the wearable sensor technology Showmotion a cadaver experiment was designed, allowing a direct comparison between sensors directly pinned to the scapula and superficial sensors. A measurement protocol was adopted to evaluate errors in measurement, mimicking the suggested in vivo evaluation. Sensors were simultaneously placed above (supraspinal) and below (infraspinal) the scapular spine to determine if one placement resulted in fewer errors compared to the other.

Results: Mean and standard deviations of the supraspinal sensor root mean square error (RMSE) in flexion-extension movements resulted in 3.59° ± 2.36°, 4.73° ± 2.98°, and 6.26° ± 3.62° for upward-downward rotation (up-down), anterior-posterior tilt and internal-external (intra-extra) rotation, respectively, while 2.16° ± 1.21°, 2.20° ± 1.02°, and 4.46° ± 2.16° for the infraspinal sensor. In abduction-adduction movements, mean and standard deviations of the supraspinal sensor RMSE resulted in 4.26° ± 2.98°, 5.68° ± 4.22°, and 7.04° ± 4.36° for up-down rotation, anterior-posterior tilt, and intra-extra rotation, respectively, while 2.38° ± 1.63°, 2.47° ± 1.77°, and 4.92° ± 3.14° for the infraspinal sensor. The same behavior was confirmed in shrug movements, where 4.35° ± 3.24°, 4.63° ± 3.09°, and 5.34° ± 6.67° are mean and standard deviations of the supraspinal sensor RMSE for up-down rotation, anterior-posterior tilt, and intra-extra rotation, respectively, while 2.76° ± 1.87°, 2.83° ± 2.53°, and 4.68° ± 5.22° for the infraspinal sensor.

Conclusion: This method of quantitative assessment of scapular motion is shown to have good accuracy and low error between the sensor measurements and actual bone movement in multiple planes of scapular motion, both over the entire range of motion and in its individual segment intervals. The decreased amount of error with the infraspinal sensor placement suggests that placement is ideal for clinical quantitative assessment of scapular motion.

The importance of scapular resting position and dynamic motion in shoulder function has been established through observational assessments, electronic 3-dimensional motion analysis, and bone pin studies.[19,20,25,28,29,34-37,41,42,55,56] The roles of the scapula are based on optimizing scapular kinematics as part of scapulohumeral rhythm.[22,37,38] Altered kinematics are termed scapular dyskinesis, which in isolation is not an injury or a musculoskeletal diagnosis but rather a physical impairment,[21] with the potential to affect arm motion, muscular strength, and joint arthrokinematics. The alteration of motion reduces the efficiency of shoulder function in several ways, including changes in 3-dimensional glenohumeral angulation, acromioclavicular joint strain, subacromial space dimensions, maximal muscle activation, and optimal arm position

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*Corresponding author: Matteo Mantovani, MSc, MBA, NCS Lab Srl, Medical Device Research Lab, Via Pola Esterna, 4/12, Carpi, 41012 MO, Italy.

E-mail address: m.mantovani@ncs-company.com (M. Mantovani).

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and motion.[21] The exact incidence of clinically significant scapular dyskinesis is not known. Most studies point to a high incidence of dyskinesis in populations that require repetitive overhead motions in their activities.[5] Sports including baseball, tennis, swimming, volleyball, cricket, kayaking, and surfing have demonstrated an incidence of 30%-70% dyskinesis.[13,16,30,39,40,49,54] Studies in symptomatic patients reveal an incidence between 64%-100% depending on the anatomic diagnosis.[14,21,27,28,35,43,59] The literature has also shown that an increased risk of shoulder pain and injury exists when scapular dyskinesis is present.[15,21] Expert opinion has recommended identification of the presence or absence of dyskinesis as part of the initial evaluation of shoulder injury, and periodic reevaluation of the kinematics as part of the progression of optimal treatment.[21] These recommendations can be best achieved by accurate methods of measurement of scapular position and motion.

Efforts have been made to better clinically categorize, classify, and identify the altered motions in the dyskinetic scapula to better guide treatment. To date, the most commonly utilized method of identifying scapular dyskinesis has been qualitative analysis by the clinician using specific observational criteria to determine if the scapula is moving in an abnormal pattern.[21] Scapular dyskinesis can be clinically observed and characterized by asymmetrical medial or inferior medial border prominence, early scapular elevation or shrugging upon arm elevation, and/or rapid downward rotation upon arm lowering.[22] The dyskinetic motion may involve alteration of one or several of the scapular motions and translations to produce the observed clinical findings. Although clinicians can become well trained at distinguishing between clinically significant and nonsignificant scapular dyskinesis,[42,55] the inherent flaw with observational analysis is the natural subjectivity of the assessment method.

Multiple methods of quantitative analysis have been proposed but have not been found to be clinically useful due to lack of consistent reliability,[44,45] limitation of data to one scapular kinematic component,[17,52,53,60] large error of the data in relation to actual bone motion,[18,32,58] or inability to use the assessment method(s) in a clinical setting due to inconveniences of cost and set-up (bone pins, electromagnetic tracking, and computed tomography scans).[28,29,38,41] As a result, even with the known limitations of qualitative analyses,[9,10] the visual observational method is still the most frequently selected by clinicians to identify the presence or absence of dyskinesis in the evaluation of the patient[26] and to make generalized assessments of change during the treatment process.

Precise and effective quantitative assessment of scapular motion in the clinical setting that encompasses all scapular kinematic components of 3-dimensional motion by a system of wearable sensors would be of great importance to assist initial evaluation and longitudinal follow-up in treatment. Ease of use, the speed in the acquisition, the usability on a routine base, and the avoidance of any specific expertise related to motion analysis techniques are advantages of wearable technology. A known limitation of a wearable sensor system is the mobility of the skin over the underlying bone, resulting in large errors between the measured motions and the actual bone motions.[31] An effective motion capture system would incorporate technology to minimize the amount of error and therefore produce a high degree of accuracy in the measurements. The Showmotion (NCS lab srl, Capri, Italy) motion capture device was developed with this goal in mind, and its standard capabilities have been reported.[7,8,46-48]

The careful selection of anatomical landmarks is a key factor in reducing skin artifacts. If the latter is not contained, the measurement error can significantly increase, leading to additional difficulties in data interpretation. Reducing the data dispersion means increasing the resolution of the methods that can be translated into increasing the capability to discriminate deviation from normal motion (ie, alterations of the kinematics). The purpose of this study was to determine the accuracy of the data obtained by the device sensors and to validate the optimal positioning of the scapular sensor in relation to the gold standard of actual bone movement. The research hypotheses were: (1) scapular motion obtained by the Showmotion device would be comparable to measurements obtained by bone pins; and (2) all scapular rotations can be assessed via the Showmotion device.

Materials and methods

Procedures

Five cadaveric shoulders were included in the data acquisition process: three left and two right shoulders. The cadaveric specimens were total body samples. Because this study aimed to simulate the use of the sensors in the clinical setting, the sensors were applied on intact external skin without altering the anatomy of the specimens via dissection with the aim of reproducing real in vivo use. Each shoulder was monitored using 3 sensors mounted on and taped to the skin according to the Inail Shoulder and Elbow Outpatient protocol (ISEO)[8] and one gold standard sensor pinned to the scapula (Fig. 1). Two sensors were mounted on the middle third of the scapular spine, just above (supraspinal) and under (infraspinal) the bone (a- and b-sensors in Fig. 1, respectively), and one skin mounted sensor was attached to the acromion (c-sensor in Fig. 1). The supraspinal and infraspinal sensor positions allowed for the assessment of the accuracy of the data since preliminary pilot studies reported variability in accuracy between the two sensor positions. None of the sensors touched each other.

The gold standard sensor (NCS Lab, Carpi, Italy) was glued to a specially designed 3-dimensional printed plastic platform (Newcast Services srl, Carpi, Italy) that was connected with the scapula through the use of threaded Kirschner wires (K-wires) (using a minimum of 3 different 1.8 mm wires). The sensor orientation on the plastic platform was to follow the scapular spine. The plastic platform (Fig. 2) was designed for this experiment to seat the additional reference sensor rigidly connected with the scapula and to minimize two undesired effects: limiting data transmission issues and limiting magnetometer interference.

The K-wires were inserted and positioned to engage the scapular body without impinging the chest. Several plastic stoppers were used to lock the platform position during the experiment and avoid undesired small oscillations or deviations from the original positioning. A stability check was done for the platform before performing the movement trials, and additional K-wires were added to fix it securely on the scapula as necessary.

Kinematic recordings

Kinematic data were acquired using Showmotion (NCS Lab, Carpi, Italy), in which the ISEO protocol was implemented for upper limb analysis.[8] The interoprator and intraoperator variability of the Showmotion system was previously described in an earlier study.[51] In the current study, 3 body segments were analyzed using magneto-inertial measurement units (MIMU): thorax, humerus, and scapula. Each MIMU provides both raw data (triaxial accelerometer, triaxial magnetometer, and triaxial gyroscope) and the orientation matrix, which represents the orientation of the local system of reference (SoR) with respect to a fixed SoR. The software collects the data in real time from all the sensors by means of a synchronized protocol and provides the 3-dimensional kinematics

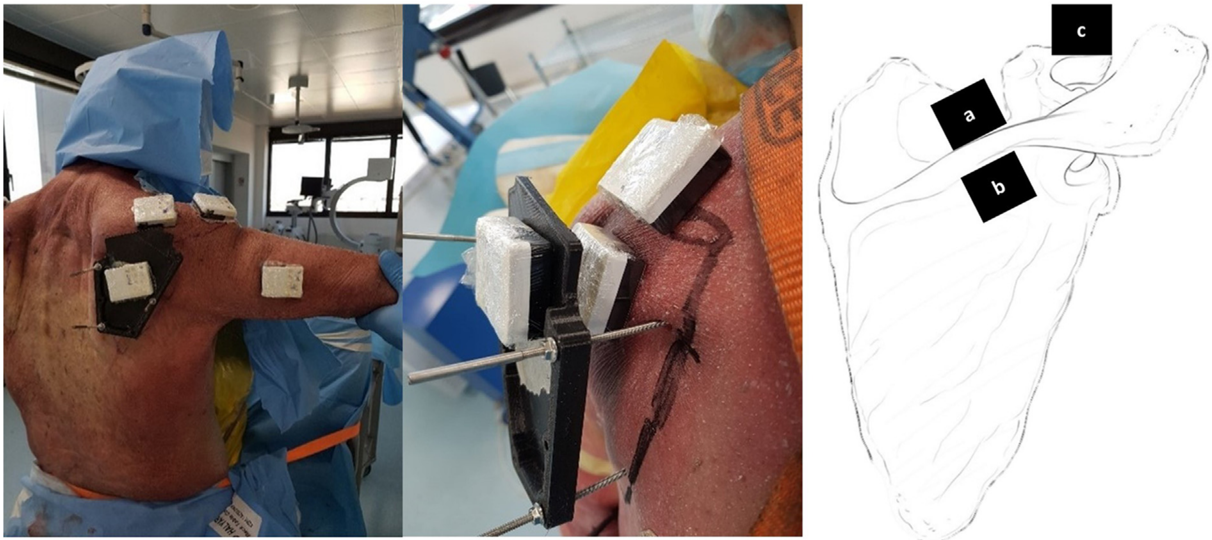


Figure 1 Sensors positioning on the experiments. Sensors are marked with letters (**a**) (supraspinal sensor), (**b**) (infraspinal sensor) and (**c**) (acromion sensor). The figure shows the different positioning of the sensors on the scapula the platform that allocate the sensor rigidly screwed to the bone.

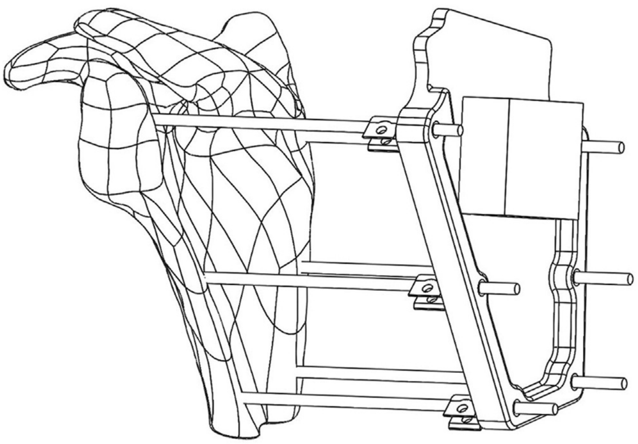


Figure 2 Plastic 3D printed platform to allocate the pinned sensor and system of fixation to the scapula.

of the joints of interest (scapulothoracic and humerothoracic joints), allowing visualization of the scapular motion as part of scapulohumeral rhythm. All data were acquired in real-time with a sampling frequency of 50 Hz. The thoracic sensor was positioned over the manubrium of the sternum, while the scapular sensors were considered as the main reference for the central one-third of the ridge of the shoulder blade. These sensors were attached to the study participants using double-sided tape (3M Health Care, St Paul, MN, USA). The sensors were aligned to the scapular spine direction. The acromion sensors were placed with the longer side parallel to the lateral aspect of the underlying bone. The humerus sensors were instead attached with dedicated Velcro straps in the mid-third of the diaphysis in the range 40°-60° in respect to the frontal plane (posteriorly). The anatomical landmarks have been identified by palpation (following recommendations from the International Society of Biomechanics) and marked with a pen before positioning the sensors. The humerothoracic and scapulothoracic angles were then obtained, sample-by-sample, by decomposing the relative orientation of the anatomical system of reference with the following sequences of Euler angles: scapulothoracic protraction-retraction (intra-extra), up-down rotation (up-down), and anterior-posterior tilting with the sequence YZ’ X”; humerothoracic flexion-extension and abduction-adduction with the sequence XZ’ Y” for almost sagittal tasks; humerothoracic abduction-adduction and flexion-extension with the sequence ZX’ Y” for almost frontal tasks.

The above described protocol has been published and used in the clinical settings by several authors.[7,8,12,51] The sensors used in this experiment were manufactured by NCS lab (Carpi, Italy).

Synchronization between all the sensors during the measurement phase is essential to allow the direct comparison of data collected by the different units, and it is assured by the protocol embedded into NCS lab MIMU sensors and into the Showmotion technology.

For each plane of shoulder elevation, scapular motion is described by three scapula-thoracic rotations (ie, upward-downward rotation, internal-external rotation, and posterior-anterior tilting) as a function of humeral flexion or humeral abduction (Fig. 3, *A-C* respectively). Once the sensors were positioned, the protocol for data acquisition of each cadaveric shoulder included both a static calibration phase and different passive movements: arm abduction-adduction, flexion-extension, and shoulder shrug movements.

During the static calibration phase lasting 5 seconds (according to the Showmotion protocol), the anatomical coordinate systems were created by the software acquiring static reference measurements with the cadaveric shoulder positioned vertically and the humerus positioned alongside the body. Passive shoulder movements were performed, keeping the cadaveric trunk erect and moving the arms in order to reach the maximum elevation in forward flexion, scapular plane abduction, and scapular shrugging. Each movement (abduction-adduction, flexion-extension, and shrug) was repeated seven times consecutively. The entire procedure was repeated three times for each cadaveric shoulder. At the end of each session, all sensors were removed and repositioned by a different operator with a complete restart of the measuring procedure. This approach made it possible to take into account the interoperator differences in sensor positioning and how the different sensor positioning affects the results. The intraoperator reliability of sensor placement has been presented in a previously published study.[51]

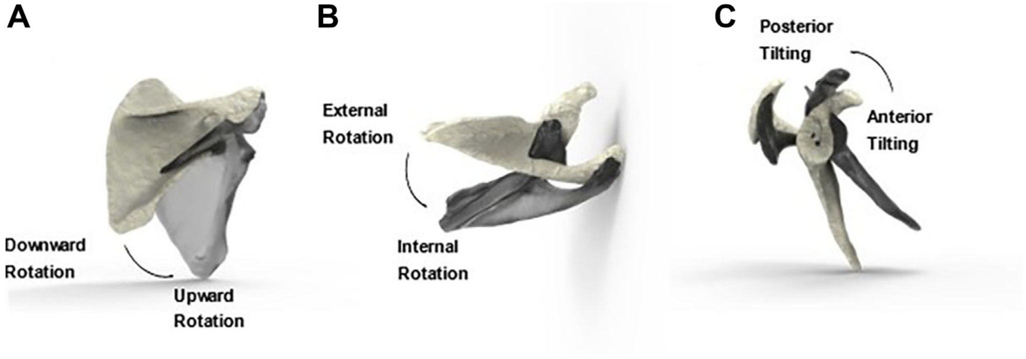


Figure 3 Main rotational degrees of freedom of the scapular blade.

Statistical analysis

Scapular motion and scapulohumeral rhythm data were calculated via the ISEO protocol utilizing the skin sensors, while gold standard data were obtained from the pinned scapula sensor representing scapula bone movement. This allowed for an analysis of the accuracy of the measurements. For each acquisition performed and for each scapula degrees of freedom, the errors were evaluated in terms of root mean square error (RMSE) with respect to the gold standard.[51] Mean and standard deviations of RMSE on all the acquisitions were consequently used to describe the overall error of the specific sensor positioning in the specific scapula degrees of freedom. This error also already includes the interoperator differences in sensors positioning. No dedicated analysis related to the specific evaluation of test and retest reliability was performed because that was already included in a previously published study.[51]

Finally, the motions in flexion, abduction, and shrug were segmented into discrete intervals as a function of humerus elevation: from 0°-30°, from 30°-60°, from 60°-90°, and over 90°, and RMSE was also calculated in each of these intervals of humeral elevation. Mean and standard deviation of RMSE of each interval on all the acquisitions were consequently evaluated to describe the error variability as a function of the humeral elevation. From this procedure, it is possible to compare how the error may change over the entire range of arm elevation and how the different sensor positionings perform in the various planes of motion. Statistical analysis was performed in order to evaluate if the differences found in the different sensor positionings are relevant, both considering the RMSE over the full humerus range of motion and considering the RMSE in the discrete intervals previously described. The normal distribution of the data was checked using the Shapiro-Wilk test. A multiple comparison test was used for pairwise post hoc analyses. Statistical analysis was performed using the Matlab (Mathworks, Natick, MA, USA) software package (version R2017b), and a *P*-value <.05 was considered statistically significant. The minimum sample size was calculated to achieve a power of 80% for ROM data analysis to detect a difference in means of 2.5° (assuming that the common standard deviation is 2, using a two group t-test with a two-sided significance level of $\alpha = 0.05$). The adequate number of tests to respect the above-reported conditions was 12. The current study performed 15 tests, which was 20% more than the minimum required.

Results

A numerical quantification of the errors of the Showmotion system, expressed as mean and standard deviation of RMSE with respect to the gold standard curves, is reported in Figure 4.

The information collected by the sensor positioned over the acromion showed a higher error and data dispersion. Because of this result, the diagrams are limited to the over and under acromion positioning. Mean and standard deviation of the RMSE over the entire range of flexion, abduction, and shrug movements, and the different scapula sensor positions are reported in Figures 5-7. The magnitude of the error varied between 2.5° and 6.0° in the infraspinal sensor placement (under). The error was minimal in upward-downward rotation and anterior-posterior tilt for all three movements and was at its maximum in the internal rotation plane.

Mean and standard deviations of supraspinal sensor RMSE in flexion-extension movements resulted in 6.26° ± 3.62°, 3.59° ± 2.36°, and 4.73° ± 2.98° for internal-external rotation, upward-downward rotation, and anterior-posterior tilt, respectively, while 4.46° ± 2.16°, 2.16° ± 1.21°, and 2.20° ± 1.02° occurred for the infraspinal sensor with respect to the same movements (Fig. 4).

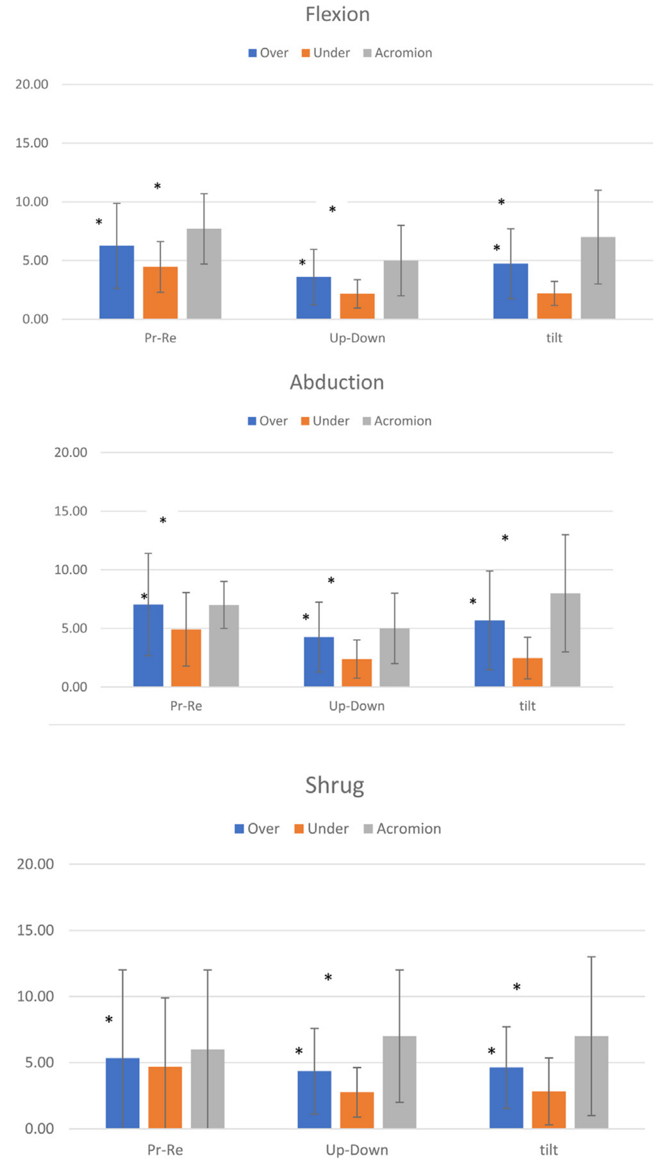
In abduction-adduction movements, mean and standard deviations of the supraspinal sensor RMSE resulted in 7.04° ± 4.36°, 4.26° ± 2.98°, and 5.68° ± 4.22° for intra-extra rotation, up-down rotation, and anterior-posterior tilt, respectively, while 4.92° ± 3.14°, 2.38° ± 1.63°, and 2.47° ± 1.77° for the infraspinal sensor (Fig. 4). Similar results occurred for the shrug movements, where 5.34° ± 6.67°, 4.35° ± 3.24°, and 4.63° ± 3.09° are mean and standard deviations of supraspinal sensor RMSE for intra-extra rotation, up-down rotation, and anterior-posterior tilt, respectively, while 4.68° ± 5.22°, 2.76° ± 1.87°, and 2.83° ± 2.53° occurred for the infraspinal sensor (Fig. 4).

Figure 4 reports the *P*-values for each degree of freedom obtained from statistical analysis comparing RMSEs of over scapula sensor with RMSEs of under scapula sensors. The difference between upper and lower spine positioning was always statistically significant, with the exception of anterior-posterior (intra-extra) angles in shrug movements.

The variability, in terms of mean and standard deviation, of the RMSE as a function of humerus elevation is presented in Figures 5-7 for flexion-extension, abduction-adduction and shrug exercises, respectively, which show an increase of the error with the increase of humerus elevation for both positionings and in all the movements. Together with the variability of the performed motions, a statistical analysis of the observed differences between the supra- and infraspinal sensors is reported in Figures 5-7 subdivided into discrete intervals of humeral elevation. Only the analysis of shrug movements was not possible due to the lack of sufficient data in the higher elevation ranges.

Discussion

The data support acceptance of the two research hypotheses. Scapular motion measured by the Showmotion device was accurate



Movement (p values)	over vs under	over vs acromion	under vs acromion
Flexion	0.15	0.20	0.02
Abduction	0.11	0.45	0.05
Shrug	0.15	0.01	0.02

Figure 4 Mean and standard deviation of the RMSE of each acquisition for flexion-extension, abduction-adduction, and shrug movements. *Supraspinal sensor placement (over) had significantly more error compared to the infraspinal sensor placement (under). The acromion sensor provides the highest error in all DOFs. In the table, the *P* values are reported for each couple of placements. *DOF*, degrees of freedom; *RMSE*, root mean square error.

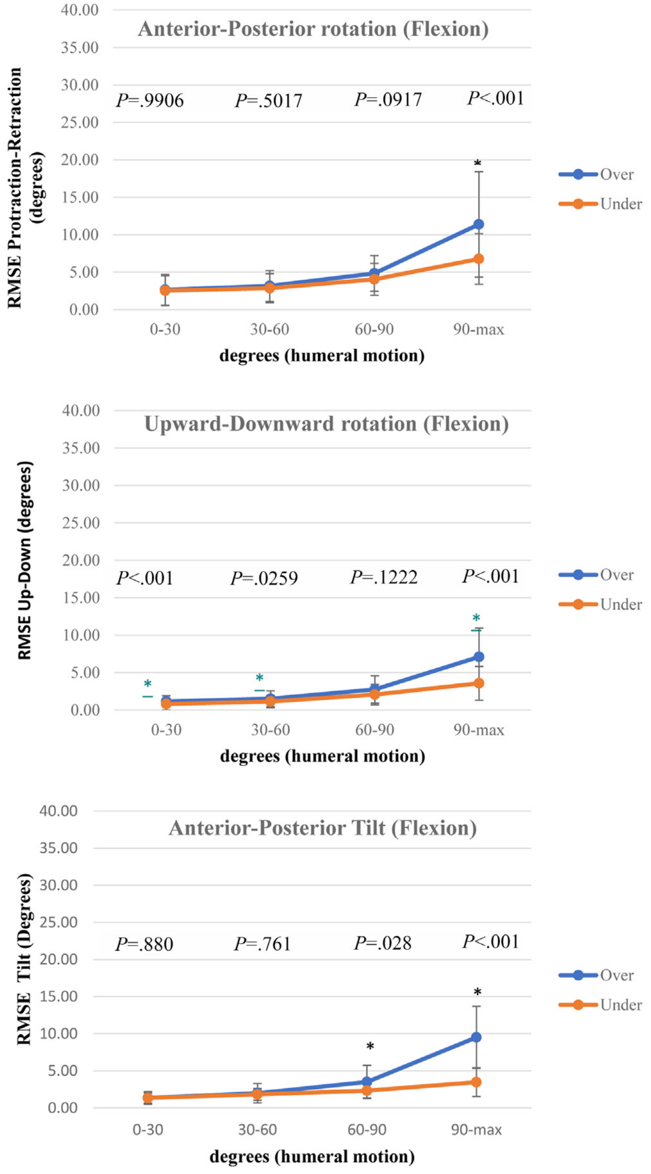


Figure 5 Mean and standard deviation of the RMSE over the entire range of flexion along the three scapular degrees of freedom. *Supraspinal sensor placement (over) had significantly more error compared to the infraspinal sensor placement (under). *RMSE*, root mean square error.

within 2.5°-6° in multiple planes of scapular motion in flexion, abduction, and shrug to the data measured by the bone pins, with the measurements especially accurate in arm motion up to 90° of elevation. Different positions of sensor placement, however, did not demonstrate statistically different data. Infraspinal positioning did consistently demonstrate smaller RMSE errors. Results indicate that few significant differences were found in the 0°-30° range of humeral elevation. More specifically, the RMSE in upward-downward rotations estimated from lower sensor positioning was consistently inferior with respect to the upper sensor (supraspinal) positioning in all the movements performed, while the RMSE in anterior-posterior tilt rotations was significantly different only in abduction and in shrug movements, and no differences were found in intra-extra rotation. These findings demonstrate that clinically accurate quantitative evaluation of scapular motion may be obtained in multiple planes of scapular motion with the Showmotion device and confirm the suitability for use in clinical settings, as previously demonstrated in other papers.[7,8,12,51] Information derived from this method of assessment could potentially add meaningful contributions regarding scapular motions to the currently available methods of clinical assessment of scapular roles in shoulder injuries, including rotator cuff injuries,[43,50] labral injuries,[3,4] as well as instability and acromioclavicular joint injuries.[6,14,23,61] The contribution to clinical use is related to the additional information the methodology brings. Beyond the numerical data associated

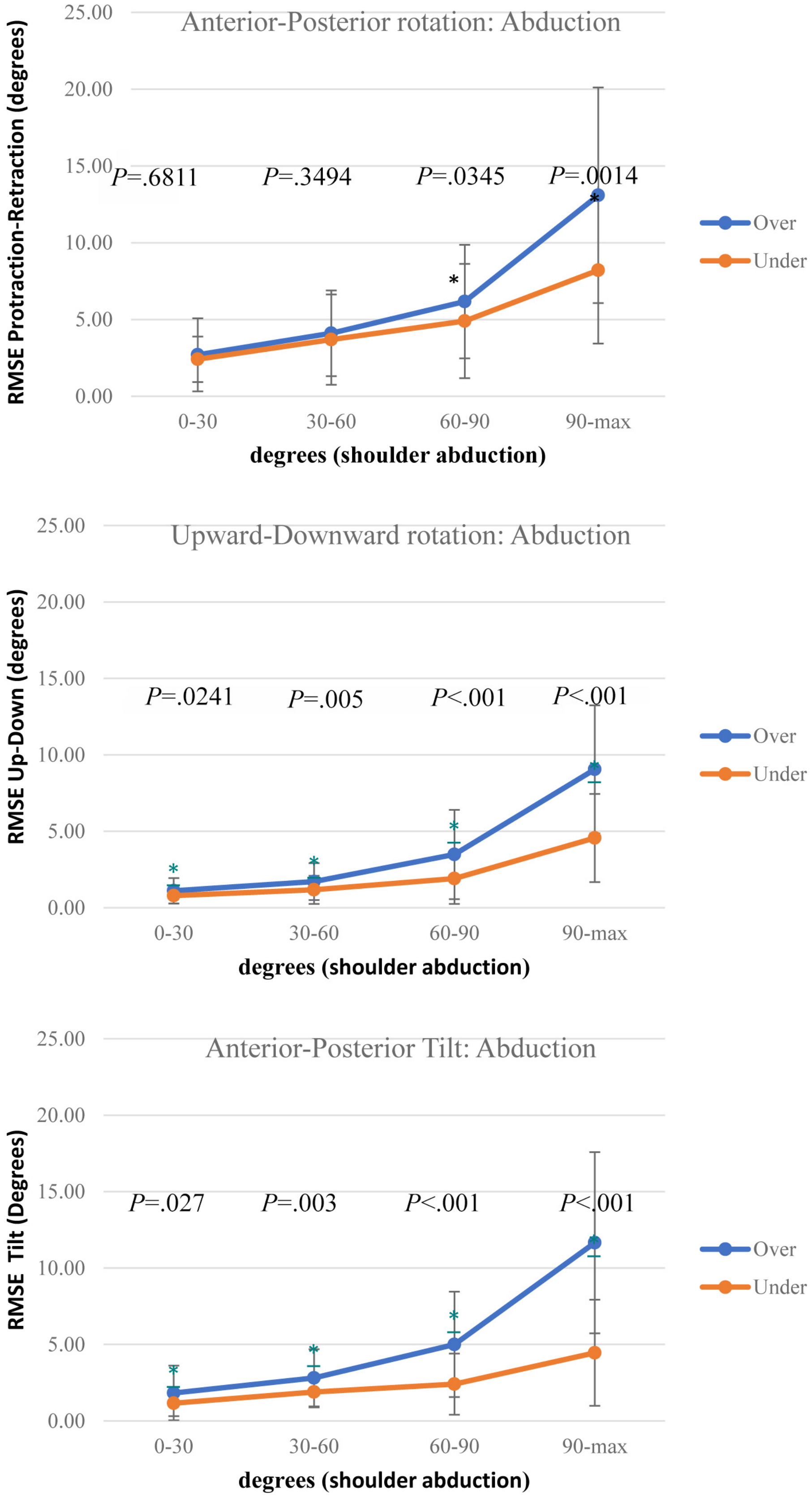


Figure 6 Mean and standard deviation of the RMSE over the entire range of abduction. *Supraspinal sensor placement (over) had significantly more error compared to the infraspinal sensor placement (under). RMSE, root mean square error.

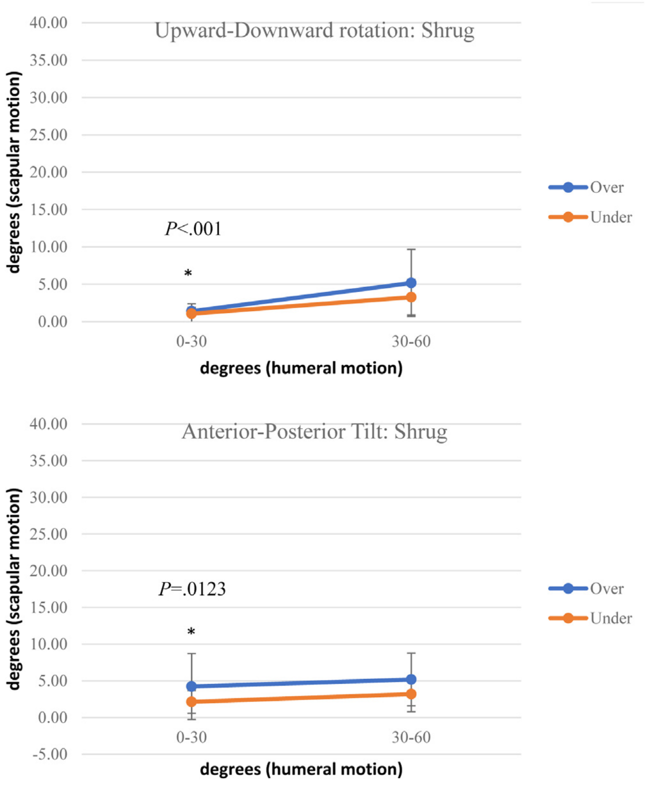


Figure 7 Mean and standard deviation of the RMSE over the entire range of shrug. *Supraspinal sensor placement (over) had significantly more error compared to the infraspinal sensor placement (under). Where not shown, the p value is not available. *RMSE*, root mean square error.

with the specific degrees of freedom of the scapula (usually the evaluation is limited to the maximum reached value), we can describe dynamic information that continually tracks the scapula movement from resting position to the peak of movement and vice versa. This dynamic information is of fundamental importance to assess because it can potentially provide clinicians insights into muscle activation sequencing throughout a range of motion and therefore, provides useful information for treatment decision-making. In other words, the ability to quantify scapular motion allows for more accurate identification of alterations, thus leading to more specified treatment programming and individualized care. The contributions of this study are important since the multiple methods of assessment of alterations in scapular motion that have been described have several limitations. Qualitative observational methods, utilizing specific criteria to create a "yes" (presence of dyskinesis) or "no" (absence of dyskinesis) framework, have been advocated,[21] can be helpful on initial evaluation but are imprecise regarding delineation of which specific scapular planes of motion may be altered,[42,55,56] and are too general to allow meaningful re-evaluation during treatment or to accurately document change in determining outcomes. Quantitative methods have been hampered by their inability to be used in clinical settings, by being limited to 2-dimensional or single-plane motion assessments,[33] or by poor reliability of the sensor data due to excessive skin motion. Errors from skin sensors have been reported to be as high as 10°.[32,46] Despite these shortcomings, multiple attempts to objectively track the scapula have been made, evidencing the need to expand the current clinical capacity. Inertial and magnetic measurements have been proposed to assess tridimensional alterations, but their applicability has not been completely established.[33] The combined use of cameras and electromyography signals have also been used to evaluate the scapular kinematics and the related muscle activity, but this was performed in nonclinical cohorts.[1,2] Some early attempts to implement sensors used in the clinical setting showed to be promising,[51] while others highlighted the use of computed tomography in mapping dyskinetic movements of the scapula.[59] Electromagnetic trackers have been used to evaluate scapular kinematics associated with a rotator cuff tear.[43] In all instances, the methodologies employed to assess scapular motion did not compare their results to the gold standard of bone pin insertion. As such, we attempted to measure the error of wireless sensors against the gold standard of bone pin insertion as a foundational step prior to carrying out human-based studies.

In this study, the accuracy in tracking scapula motion using the Showmotion system was assessed by comparing the kinematic output generated by Showmotion scapular sensors, placed over the skin, with the kinematic output generated by the data collected by a gold standard sensor that was pinned to the scapula. This comparison could identify errors in scapula kinematic measurement introduced by soft tissue artifacts. The RMSE errors over the entire range of scapular motion as the arm moved from 0° to maximum elevation in flexion, abduction, and shrug were 2.5°-5°. These error values are smaller than previously reported[17,36,46] and represent a small percentage of the total possible scapular motion capability in each of the planes of motion.

RMSE was also evaluated in each segment interval of humerus elevation in flexion, abduction, and shrug, and they show an increase in error with the increase in humerus elevation, for both scapular spine positionings and in all the planes of motion. In the first 60° of humerus elevation in all planes, the errors in scapula kinematic estimation are very small, and the error values at 90° were greater but still small percentages of the entire motion capability in each plane. This is felt to be due to the precision of the anatomical coordinates resulting from the static calibration procedure performed at the beginning of each session of acquisition and the relatively smaller amount of bone movement under the skin and smaller muscle activations in the early phases of scapular motion. The high level of accuracy at lower levels of arm elevation is felt to be important in clinical practice because most current opinion suggests that stabilization of the scapula in the early phases of scapulohumeral rhythm is key to coordinated function throughout all the scapulohumeral rhythm motion, so precise evaluation of this key time in scapulohumeral rhythm is of high clinical importance.[11,24,57]

The data regarding the positioning of the sensor on the scapular spine showed no statistically significant difference in the RMSE error in the overall motions, and the pattern of the change in the amount of the error within each segment interval during increased arm elevation in each plane is consistent across each of the motions. However, over the entire range of motion and in the individual segment interval of each motion, the infraspinal position consistently demonstrated the lowest error, especially at the higher levels of arm elevation. For these reasons, infraspinal positioning is considered the position of choice.

Limitations

There are several limitations to this study. The first is the number of cadaver specimens. The "N" of 5 may lead to insufficient data to report all statistically significant differences. Although an increase in the number of cadaveric specimens would possibly increase the external validity by accounting for the basal metabolic index variability, the sample did allow the investigation to satisfy the power analysis requirements. Second, the arm motions were all passive, with no muscle activation to motor or guide the scapular motions. This may introduce some bias into the individual scapular planes of motion or movement of the skin. Finally, the motions were all in single planar patterns along specific axes, so while the data reflects motion in multiple planes, not all possible 3-dimensional motions were represented in the data collection.

Conclusions

This method of quantitative assessment of scapular motion is shown to have good accuracy and a low error between the sensor measurements and actual bone movement in multiple planes of scapular motion, both over the entire range of motion and in its individual segment intervals. The least amount of error in scapular motion achieved when using this specific technology will occur when positioning the scapular-based sensors below the scapular spine, abutting the bony landmark from the inferior aspect.

Disclaimers:

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Conflicts of interest: Matteo Mantovani is a stockholder in NCS lab srl. Aaron Sciascia and Benjamin W. Kibler are paid consultants for NCS, Inc. and receive royalties for coediting two textbooks for Springer Publishing. Marco Muraccini is an employee in NCS lab srl. Alessandro Varini is a consultant for NCS lab srl. Fabrizio Nardini is an employee in NCS lab srl. Pietro Tonino is a paid consultant for NCS, Inc. and Linvatec.

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