RESEARCH PAPER

Reliability and Validity of a Novel Sensor-Based Technology for Bilateral Translatory and Rotatory Scapular Movement Assessment

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Abstract

Background

The scapula is very important for keeping the shoulder working and stable. To find dysfunction and plan rehabilitation, it's important to accurately measure its movement. Current clinical instruments frequently assess only discrete scapular movements and are predominantly dependent on examiner interpretation, thereby constraining their capacity to deliver thorough and objective multi-planar evaluation.

Aim

To assess the inter-rater and intra-rater reliability, as well as the concurrent validity, of a newly developed sensor-based device intended to measure both translatory and rotational scapular movements in young asymptomatic individuals

Methodology

We found fifty healthy volunteers between the ages of 18 and 25. The device recorded bilateral scapular translation and rotation at standardized arm positions. Two examiners measured things on their own to find inter-rater reliability, and two tests done 24 hours apart were used to find intra-rater reliability. We checked for concurrent validity by comparing the device's measurements to those of a digital caliper and an inclinometer. We figured out the intraclass correlation coefficients (ICC), Pearson correlation coefficients, standard error of measurement (SEM).

Result and Analysis

For translatory measures, inter-rater reliability was moderate to good (ICC = 0.734–0.853), and for most rotatory measures, it was excellent (ICC = 0.934–0.974). However, for inward–outward rotation at 180°, it was only moderate reliable. Intra-rater correlations exhibited consistent strength across all variables (r = 0.767–0.989). The validity analysis showed that there was moderate to good agreement with standard tools, with small mean differences and error values that were acceptable in a clinical setting.

Conclusion

The device showed that it could accurately and consistently measure multi-planar scapular assessment in healthy people. Its integrated method for measuring translatory and rotational movement makes it useful for clinical evaluation and rehabilitation monitoring.

Keywords: non-invasive device, medical device, clinical assessment , objective assessment

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Introduction

The shoulder complex is one of the most mobile and also the most susceptible to injury regions of the human body. The shoulder blade is a key player in maintaining the proper functioning of the shoulder. The shoulder blade plays several important roles, such as being a base that is mobile for the arm, transmitting forces through the shoulder girdle and synchronizing the movement of the arm and shoulder.[1] Over the last 20 years, researchers have increasingly realized that besides its upward rotation, the scapula also has to do with and posterior tilt and external rotation and thus, has been contributing to the mechanics of the shoulder and the performance of the upper body in overhead activities.[2] The assessment of the scapula is important in the rehabilitation of back and musculoskeletal problems because it is the main factor in the coordination of shoulder motion and the maintenance of proximal postural control.

There is no shortage of biomechanical evidence yet the application of these findings in the clinic is still inconsistent. Abnormal scapular motion, or scapular dyskinesis, which is characterized by altered scapular position or movement during dynamic activities, has been implicated in pain, cuff injury and shoulder instability.[3] One systematic review found that athletes

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with scapular dyskinesis were 43% more likely to experience shoulder pain in the future than those without it.[4] On the one hand, proper clinical measurement of scapular motion is difficult due to the fact that the scapulothoracic joint moves in three dimensions along curved thoracic surfaces and is mainly covered by soft-tissue.[5]

A recent scoping review pointed out that the methods to quantify scapula movements in one direction are numerous but most of these focus only on static or singular motions—mainly upward rotation—without being able to deal with dynamic, multi-planar, bilateral scapula movements in an easy and practical manner. Multiplanar movements of the scapula have always been assessed through the gold standard methods like radiography, magnetic resonance imaging (MRI) and bone pins, providing kinematic data with very high accuracy but at the same time being invasive, expensive and not suitable for use in daily clinical practice [6,7–9]. Video-based 3D motion analysis and 3D electromagnetic tracking are among the non-invasive reference standards that have been validated against the criterion techniques by showing good results. However, their application is limited due to high costs, complex data processing and restriction to laboratory setting [8,9].

As a result, clinical assessment frequently depends on the use of observational and palpation methods, which are not objective measurements and are affected by the experience of the examiner [10]. The development of digital inclinometers that are gravity-referenced provided a significant breakthrough in this regard; Johnson and colleagues found good to excellent intrarater reliability (ICC 0.89–0.96) and moderate to good validity for the measurement of scapular upward and downward rotation in the frontal plane [10], and Scibek and Carcia also reported excellent reliability (ICC 0.97–0.99) for anterior and posterior tilt in the sagittal plane [11]. The devices, although good for objective measurements, were still restricted to single-plane angular measurements, and could not assess translatory movement or compared the two scapulae.

The gap between the invasive laboratory systems and the clinically feasible but incomplete devices left a spectrum of the need for an integrated and non-invasive instrument that would evaluate both the translatory and rotatory motion of the scapula. The present study aims to fill this gap by investigating the reliability and validity of a new sensor-based device designed for comprehensive evaluation of multi-planar scapula motion. For this reason, the demand for objective and user-friendly devices, which can measure, at the same time, the translatory and rotatory movements of the two scapulas in all three planes, is very high.

To tackle this, a new sensor-based prototype was created with the aim of simultaneously assessing the translational and rotational motion of the scapula in a clinical setting. The present study intends to evaluate this device's reliability and validity in a population of healthy participants, with the ultimate aim of improving the physiotherapy practice, rehabilitation monitoring, and clinical recordings of scapula kinematics.

2. Purpose of the Study

The main aim was to create and validate a safe, sensor-based system that is able to measure the bilateral movements of the scapula both in terms of displacement and rotation. The secondary objectives were to determine intra and inter-rater reliability and to see how well the system agrees with clinical standard reference tools.

3.1 Participants

This is a prospective study of methodological diagnostic accuracy. According to COSMIN, the minimum number of participants should be 30 however the study included a total of fifty young asymptomatic individuals in order to enhance precision, decrease variance, and fortify the reliability and validity estimates. The age of the participants ranged from 18 to 25 years, and they were all healthy, with no previous shoulder problems, surgeries, or diagnoses of any kind in the upper limb or spine such as musculoskeletal or neurological disorders. Every applicant was able to perform the complete active range of motion of both upper limbs and was able to raise their arms to 180° in both the frontal and sagittal planes. Only those who agreed that no medical conditions existed which could possibly affect the movement of upper limbs were considered to be eligible. The participants had to come for two assessment sessions with at least 24 hours interval from one another. The recruitment was done through convenience sampling among college-going young adults who were willing to participate in the study and who were also able to keep the study's time schedule. STARD reporting guidelines were followed.

3.2 Device Description

The prototype consists of:

•Two angle measuring units placed at the sides to measure and capture angles of the movement of both the shoulders.

•A central unit with linear sensors to measure and record the movements of the scapula in a transverse direction.

The central display provides a view of all the measurements, while the device is operated by the buttons on the device itself.

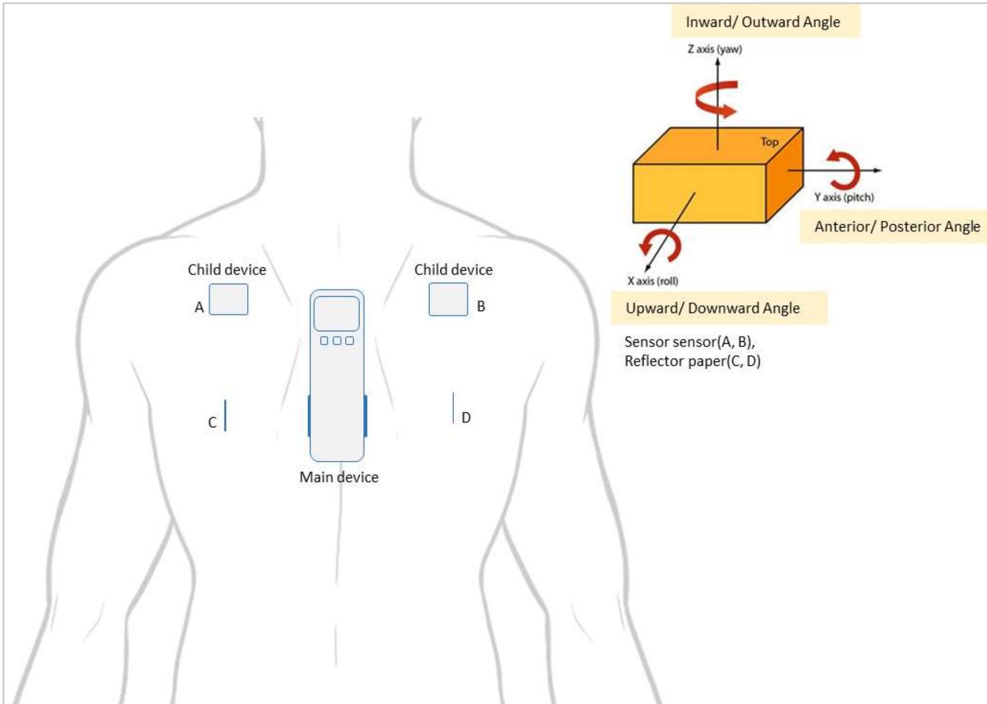

Figure 1: Overview Diagram

3.3 System Architecture

The device adopts a Wi-Fi-enabled server-client model:

- The main device serves as the server.
- The angle measuring units act as the clients, sending angular data via wireless communication.

After that, the server receives, analyses, and shows the movements of scapula in real-time.

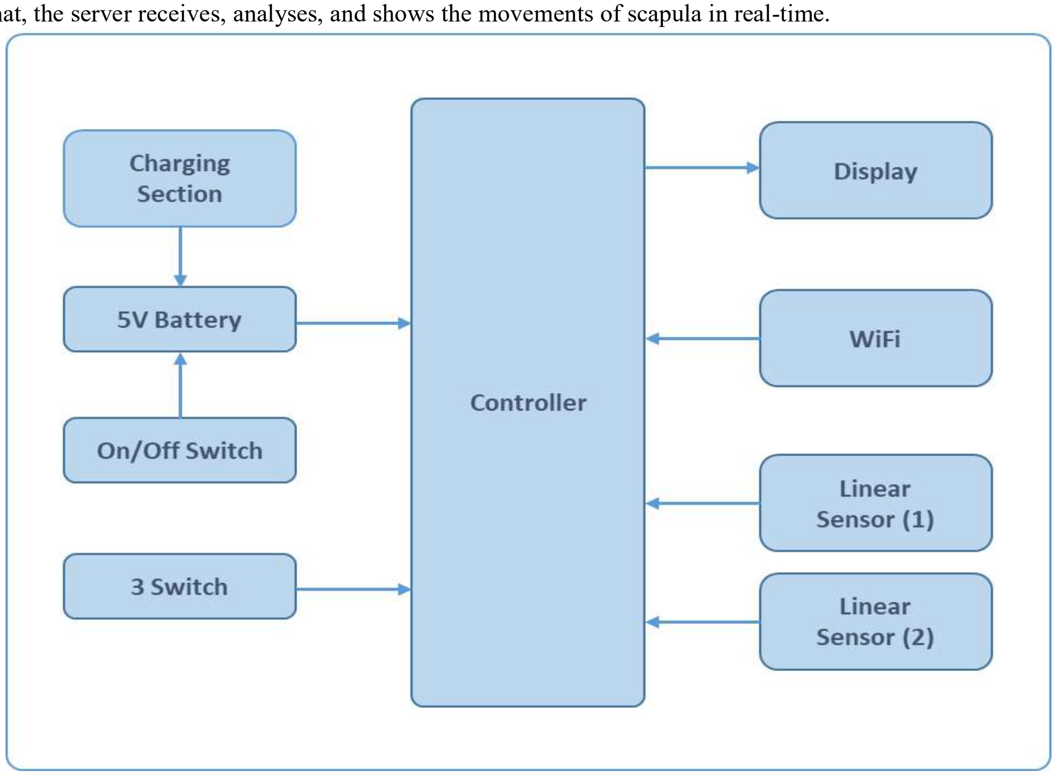

Figure 2: Main Device Block Diagram

Figure 3: Device Prototype

3.4 Procedure

Study Setting

The experiment was performed in a clinical laboratory that was controlled and well-lighted and had a comfortable room temperature The entire testing process was conducted in a private cubicle to ensure the participants' privacy and to make them comfortable both physically and psychologically during the evaluation.

Participants

The participants were selected after getting the approval of the Institutional Ethics Committee and were then screened according to the already set inclusion and exclusion criteria. The ones who passed the screening were told about the purpose of the study and the methods used and, written informed consent was taken before starting any assessment.

Preparation for Assessment

The upper back of the male participants was made visible while the female participants were dressed in tight tank tops that allowed perfect observation of both shoulders and the spine. Standard bindi markers were put on anatomically defined points which were:

1. Spine of the scapula
2. Midpoint of the medial border
3. Inferior angle

Assessor Training

One single trained assessor, who was adapt in the identification of musculoskeletal landmarks and the measuring of scapular motion, executed all assessments. The assessor practiced the steps before the official data gathering to make sure of getting familiar with the procedure and of having consistent measurements. For the determination of inter-class reliability, two physiotherapists, who were experts and trained for assessment with this device, evaluated the scapular motion. On the other hand, for intra-class reliability, the subjects were assessed with a twenty-four-hour interval between the two readings by same assessor.

Instrumentation and Calibration

The device was calibrated according to the operational protocol, this being the standard procedure that was followed before each assessment session. The digital vernier caliper and the inclinometer were zero-error checked before being used. The same conditions were maintained for all the instruments during each participant's assessment.

Participant Positioning and Measurement Conditions

The participants were barefoot and their feet were placed apart at shoulder width, arms by their sides, and their gaze was directed straight ahead. To keep the neutral posture without trunk compensation, verbal cues were given. Measurements were only performed when the posture was stable and could be reproduced.

Outcome Assessment Protocol

• **Translatory movement validity testing**: Three thoracic spinal levels were measured with the new device and a standard digital vernier caliper while the multi-point static assessment at 0° and 180° shoulder flexion.

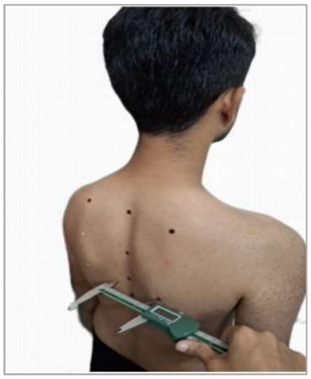

Figure 4: Translatory movement measurement with digital vernier caliper

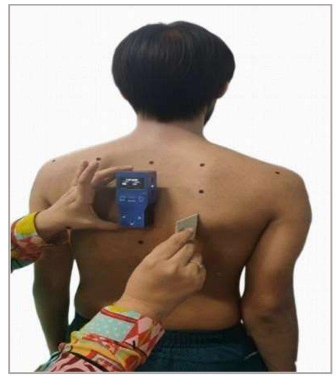

Figure 5: Translatory movement measurement with the device

• **Rotatory movement validity testing**: The device and a BASELINE Digital inclinometer were used to make rotatory measurements except internal and external rotation at 0° and 180° shoulder flexion.

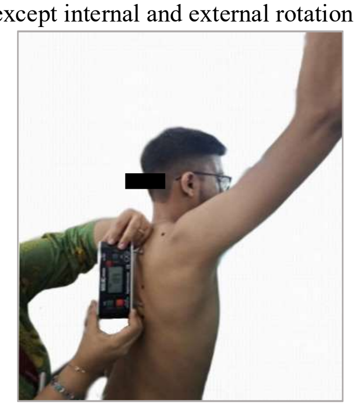

Figure 6: Anterior-posterior tilt measurement with Baseline digital inclinometer

Figure 7 : Anterior-posterior tilt measurement with the device

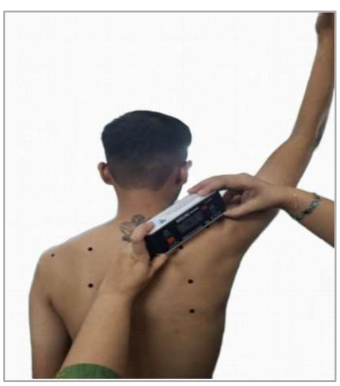

Figure 8: Scapula upward downward rotation with Baseline digital inclinometer

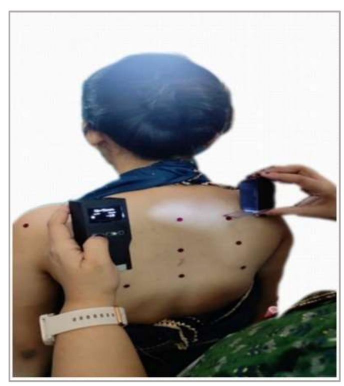

Figure 9 : Scapula upward downward rotation with the device

3.5 Data Analysis

All measurements were finished; there were no missing data points. The assessment of reliability was made by means of Intraclass Correlation Coefficient (ICC), Standard Error of Measurement (SEM), and Root Mean Square Error (RMSE). Validity was established through Pearson correlation analysis. There were no indeterminate results because all of the data were in numbers.

Table 1. Inter-rater reliability for translatory movements (ICC 2,1)

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Scapular Landmark	Side	ICC	SEM	df1	df2	p-value	95% CI (Lower)	95% CI (Upper)	Interpretation
Inferior Angle	LT	0.734	3.71	49	49.0	<0.001	0.530	0.849	Moderate
Inferior Angle	RT	0.766	4.31	49	49.9	<0.001	0.590	0.867	Moderate
Mid-Medial Border of Scapula	LT	0.830	5.92	49	50.0	<0.001	0.702	0.903	Good
Mid-Medial Border of Scapula	RT	0.829	5.89	49	49.8	<0.001	0.699	0.903	Good
Spine of Scapula	LT	0.853	6.89	49	49.4	<0.001	0.741	0.916	Good
Spine of Scapula	RT	0.794	5.10	49	43.7	<0.001	0.632	0.884	Good

- RT refers to Right Side & LT refers to Left Side

Inter-rater reliability testing for the translatory movements of scapula revealed moderate to good agreement for all the 3 landmarks measured. The reliability of the inferior angle showed moderate but statistically significant values for both sides (Left ICC = 0.734, Right ICC = 0.766). The mid-medial border and spine of the scapula exhibited good reliability with ICC values between 0.794 and 0.853, indicating consistent measurements between evaluators. All outcomes were statistically significant at $p < 0.001$, implying that the likelihood of chance effect was very low. The SEM was in the range of 3.71 – 6.89 mm, which can be considered as acceptable measurement precision for clinical application.

Table 2. Inter-rater reliability for rotatory movements (ICC 2,2)

Movement Category	Variable	ICC	F	df1	df2	p-value	95% CI (Lower)	95% CI (Upper)	Interpretation
Upward / Downward	RT at 0°	0.942	17.1	49	49.1	<0.001	0.898	0.967	Excellent
Upward / Downward	RT at 180°	0.934	14.8	49	49.0	<0.001	0.883	0.962	Excellent
Upward / Downward	LT at 0°	0.940	16.2	49	49.0	<0.001	0.893	0.966	Excellent
Upward / Downward	LT at 180°	0.972	34.9	49	49.0	<0.001	0.950	0.984	Excellent
Inward / Outward	RT at 0°	0.968	30.9	49	49.1	<0.001	0.944	0.982	Excellent
Inward / Outward	RT at 180°	0.671	3.03	49	49.9	<0.001	0.422	0.813	Moderate
Inward / Outward	LT at 0°	0.773	4.33	49	49.0	<0.001	0.598	0.871	Moderate
Inward / Outward	LT at 180°	0.965	28.4	49	49.0	<0.001	0.939	0.980	Excellent
Anterior/Posterior Tilt	RT at 0°	0.966	28.6	49	49.1	<0.001	0.939	0.981	Excellent
Anterior/Posterior Tilt	RT at 180°	0.974	39.1	49	49.1	<0.001	0.954	0.985	Excellent
Anterior/Posterior Tilt	LT at 0°	0.956	22.4	49	49.2	<0.001	0.923	0.975	Excellent
Anterior/Posterior Tilt	LT at 180°	0.947	19.3	49	49.0	<0.001	0.907	0.97	Excellent

- RT refers to Right Side & LT refers to Left Side

Rotatory movements showed excellent reliability with ICC values exceeding 0.93 for the upward rotation at both 0° and 180° positions for bilateral sides. The scapular inward-outward rotation displayed mixed reliability with three measurements showing excellent ICC values (≥ 0.897), while the right side at 180° indicated moderate reliability (ICC = 0.671), which suggests examiner-dependent variability might be present at higher humeral elevation. Scapular anterior-posterior tilt showed excellent reliability at all angles and sides (ICC range = 0.947 – 0.974, $p < 0.001$), signifying that the reproducibility was stable.

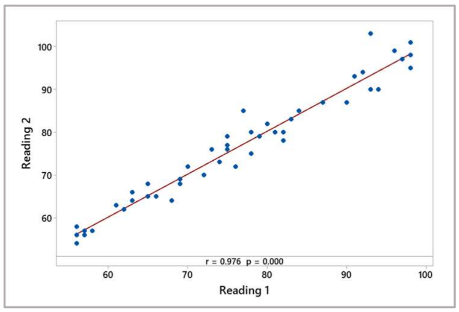
Table 3. Intra-rater reliability for translatory movements (Pearson r)

Landmark	r	95% CI	p-value	Interpretation
Inferior Angle LT	0.976	0.958–0.986	<0.001	Excellent
Inferior Angle RT	0.989	0.980–0.994	<0.001	Excellent
Medial Border LT	0.968	0.945–0.982	<0.001	Excellent

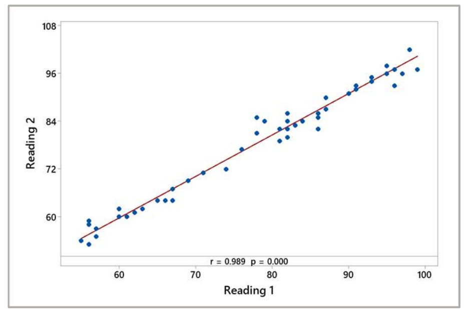
Landmark	r	95% CI	p-value	Interpretation
Medial Border RT	0.978	0.961–0.987	<0.001	Excellent
Spine LT	0.966	0.941–0.981	<0.001	Excellent
Spine RT	0.971	0.950–0.984	<0.001	Excellent

- RT refers to Right Side & LT refers to Left Side

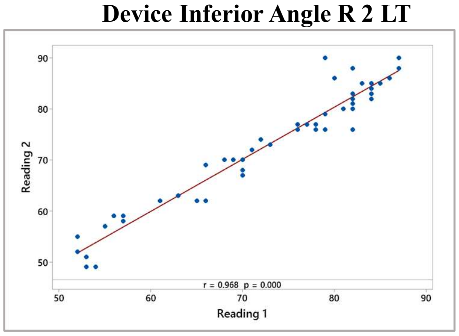
The intra-rater comparisons revealed very strong correlation values (r = 0.966 – 0.989, p < 0.001) over all translatory measurements with very narrow confidence intervals, which reflects excellent repeatability of measurement, confirming that both readings were almost identical on repeated assessment.



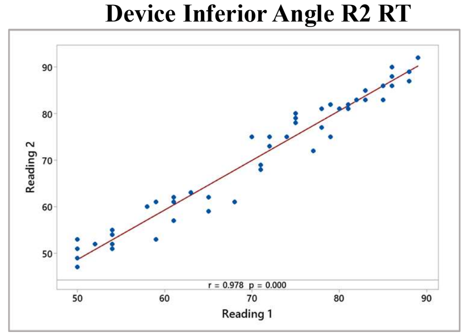
Graph 1:Device Inferior Angle R 1 LT Vs Device Inferior Angle R 2 LT



Graph 2 : Device Inferior Angle R1 RT Vs Device Inferior Angle R2 RT



Graph 3 :
Mid Of Medial Border of Scapula device R1 LT Vs Mid Of Medial Border of Scapula device R2 LT

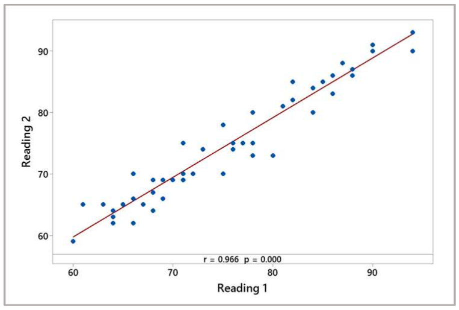


Graph 4:
Mid of Medial Border of Scapula device R1 Rt Vs Mid of Medial Border of Scapula device R2 RT

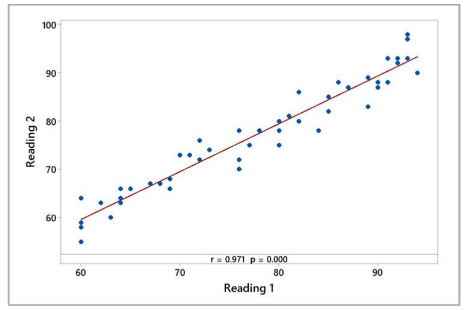
Table 4. Intra-rater reliability for rotatory movements (Pearson r)

Variable	r	95% CI	p-value	Interpretation
Upward / Downward RT at 0°	0.767	0.621–0.861	<0.001	Good
Upward / Downward RT at 180°	0.843	0.738–0.908	<0.001	Good
Upward / Downward LT at 0°	0.801	0.673–0.883	<0.001	Good
Upward / Downward LT at 180°	0.823	0.707–0.896	<0.001	Good
Inward / Outward RT at 0°	0.897	0.825–0.941	<0.001	Excellent
Inward / Outward RT at 180°	0.886	0.806–0.934	<0.001	Excellent
Inward / Outward LT at 0°	0.896	0.823–0.940	<0.001	Excellent
Inward / Outward LT at 180°	0.827	0.712–0.898	<0.001	Good

Variable	r	95% CI	p-value	Interpretation
Anterior/Posterior Tilt RT at 0°	0.933	0.885–0.962	<0.001	Excellent
Anterior/Posterior Tilt RT at 180°	0.971	0.950–0.984	<0.001	Excellent
Anterior/Posterior Tilt LT at 0°	0.964	0.938–0.980	<0.001	Excellent
Anterior/Posterior Tilt LT at 180°	0.970	0.948–0.983	<0.001	Excellent



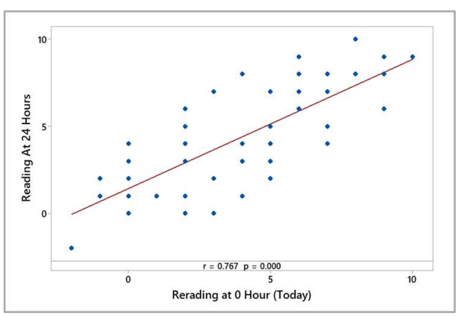
Graph 5: Spine of Scapula device R1 LT Vs Spine of Scapula device R2 LT



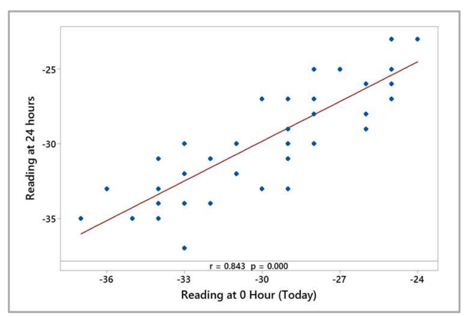
Graph 6: Spine of Scapula device R1 RT Vs Spine Of Scapula device R2 RT

R1 represents the assessment measures obtained by the first assessor; R2 represents the assessment measures obtained by the second assessor.
RT refers to Right Side & LT refers to Left Side

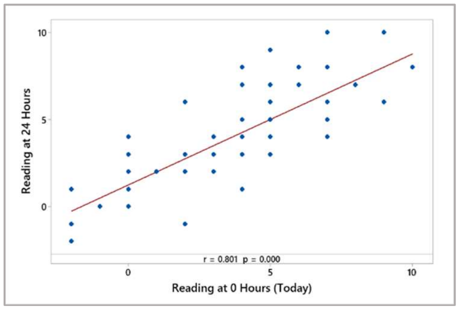
Intra-rater agreement exhibited the whole range from good to excellent correlation across all rotational measurements. The reliability of upward rotation was from 0.767 to 0.843, as the inward-outward rotation and anterior-posterior tilt showed even higher agreement values (0.886-0.971, $p < 0.001$), which means that the device can be trusted to reproduce the measurements of the angles accurately over the course of the sessions.



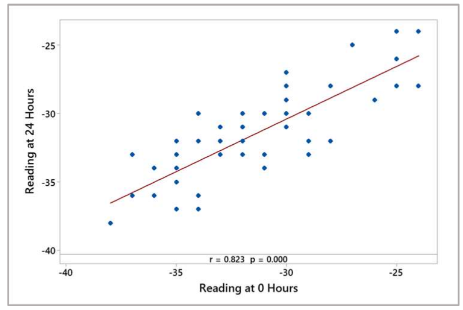
Graph 7: Upward-downward rotation Rt session 1 At 0 deg Vs Rt session 2 At 0 deg



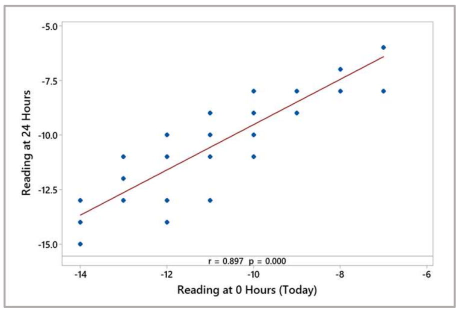
Graph 8: Upward-downward rotation Rt session 1 at 180 deg Vs Rt session 2 at 180 deg



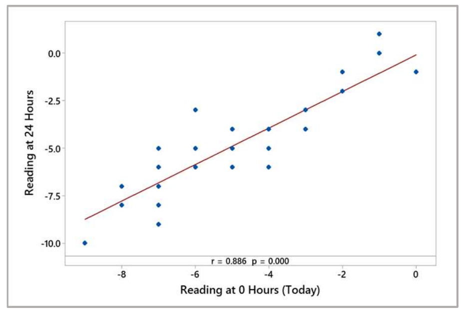
Graph 9: Upward-downward rotation
Lt session 1 at 0 deg Vs
Lt session 2 at 0 deg



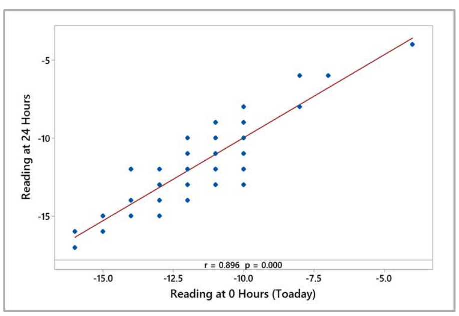
Graph 10: Upward-downward rotation
Lt session 1 at 180 deg Vs
Lt session 2 at 180 deg



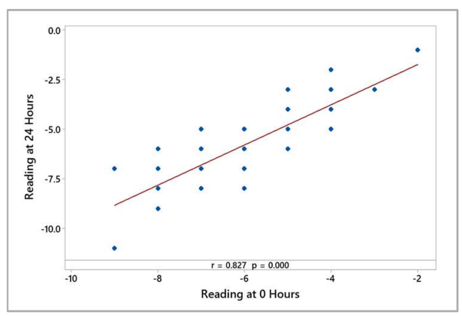
Graph 11: Inward outward rotation
Rt session 1 at 0 deg Vs
Rt session 2 at 0 deg



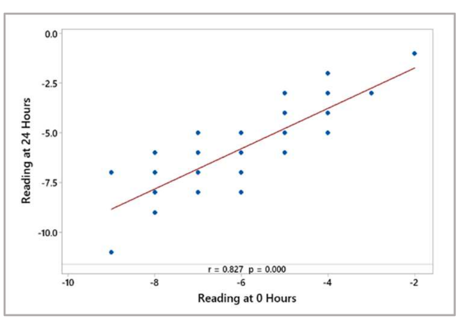
Graph 12: Inward outward rotation
Rt session 1 at 180 deg
Rt session 2 at 180 deg



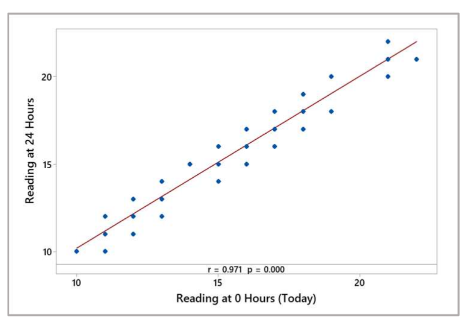
Graph 13: Inward outward rotation
Lt session 1 at 0 deg Vs
Lt session 2 at 0 deg



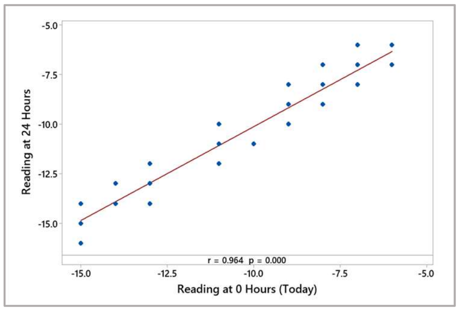
Graph 14: Inward outward rotation
Lt session 1 at 180 deg
Lt session 2 at 180 deg



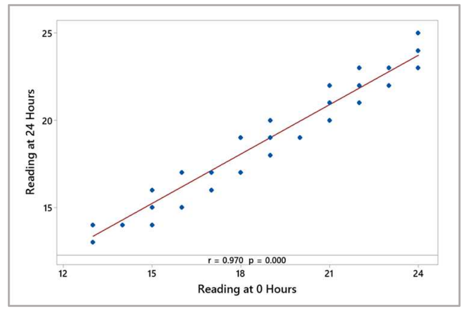
Graph 15: Anterior-posterior tilt
Rt session 1 at 0 deg Vs
Rt session 2 at 0 deg



Graph 16: Anterior-posterior tilt
Rt session 1 at 180 deg
Rt session 2 at 180 deg



Graph 17: Anterior-posterior tilt Lt session 1 at 0 deg Vs Lt session 2 at 0 deg



Graph 18: Anterior-posterior tilt Lt session 1 at 180 deg Lt session 2 at 180 deg

Session 1 denotes the measurements taken on Day 1,
Session 2 denotes the same measurements recorded after 24 hours

The concurrent validity testing for translatory measurements revealed moderate to good agreement between the device prototype and the digital caliper measurements (ICC = 0.724 – 0.854) and between the device prototype and digital inclinometer (0.733 – 0.787) for rotatory measures. The standard error of measurement was still within the acceptability range (3.8 – 7.1), while the minimal detectable change (MDC90) values pointed to clinically acceptable sensitivity for the support of change detection. The Bland-Altman values proved very small mean differences in the range of –4.78 mm to –1.56 mm, thus confirming the levels of acceptable agreement without systematic bias.

Narrative Summarization

The analyses through different raters and the one through the same rater showed moderate to excellent reliability for all the measurements of the scapula in a translatory and rotary manner. The translatory measures were harder to obtain since they were more dependent on the examiner, whereas the rotational measures showed trial-to-trial similarity of the strongest kind. The reliability and correlation values, which were all significant at $p < 0.001$, proved the stability of the measurement performance of the device under the repeated evaluation conditions.

Discussion

The current study assessed the reliability and validity of a newly developed sensor-based device intended to measure translational and rotational scapular movements. In general, the results showed moderate to excellent inter-rater and intra-rater reliability. Rotational variables were consistently more reproducible than translatory measures. This pattern is consistent with previous findings in scapular kinematic research, where upward rotation and anterior–posterior tilt generally produce greater concordance due to enhanced bony alignment and more pronounced movement patterns (Ludewig & Reynolds, 2009; Cools et al., 2014).[12,13]

The device demonstrated exceptional inter-rater reliability (ICC 0.934–0.974) for upward rotation and anterior–posterior tilt at both 0° and 180°, aligning with measurements obtained from digital inclinometers and electromagnetic tracking systems under controlled conditions. Translatory measures exhibited moderate to good reliability (ICC 0.734–0.853), indicating the impact of soft-tissue layers, palpation variability, and nuanced discrepancies in landmark identification—elements recognized as contributors to variability in manual scapular assessment (McClure et al., 2009; Struyf et al., 2014)[14,15,16]

Intra-rater consistency was outstanding for both translatory and rotatory measures, with correlation coefficients surpassing 0.96 for the majority of variables. This means that after getting to know the device, one examiner can get very accurate measurements over and over again. The validity analysis demonstrated moderate to good concordance with standard instruments, and the minimal mean differences across variables indicate that the new device yields measurement values comparable to established methods, while providing the additional benefits of bilateral, multi-planar assessment and integrated linear-angular data capture, which are not offered by current tools. The validity analysis indicated moderate to strong concordance with traditional instruments, and the minimal mean discrepancies among variables imply that the new device yields measurement values akin to established methodologies, while providing the additional benefits of bilateral, multi-planar evaluation and integrated linear-angular data acquisition, which are absent in current tools.

Nonetheless, various constraints must be acknowledged. The sample comprised exclusively healthy young adults, thereby limiting generalizability to clinical populations. People with shoulder problems may show different ways of moving that could affect the stability of measurements. Landmark palpation persists as a source of variability; although the extent of this bias is minimal, it is intrinsic to surface-based scapular assessment methodologies. Furthermore, validity was evaluated using clinical instruments instead of three-dimensional motion analysis, which constrains comparison with gold-standard laboratory data.

Even with these limitations, the results show that this prototype could be used as a clinical measurement tool. Subsequent research ought to concentrate on evaluating the device within symptomatic populations, contrasting it with sophisticated motion-capture systems, and assessing its responsiveness to therapeutic interventions.

Conclusion

The newly designed sensor-based device exhibited reliable and repeatable measurements for both translational and rotational scapular movements in healthy young adults. Inter-rater and intra-rater analyses demonstrated moderate to excellent reliability, while validity testing indicated satisfactory concordance with standard clinical instruments. The device provides a unified approach to evaluating bilateral scapular motion across various planes, potentially facilitating clinical assessment and mitigating the constraints inherent in conventional single-plane or single-tool methodologies. These results suggest that the prototype may evolve into a functional and objective instrument for scapular evaluation in physiotherapy and sports rehabilitation contexts. Additional testing in symptomatic and athletic cohorts will enhance its relevance in broader clinical practice.

Clinical implications and strengths of the study

This study yields significant clinical value by enabling physiotherapists to use one device that assesses both translatory and rotatory movements of the scapula, thus minimizing the need for various measuring instruments and allowing more objective and repeatable evaluations. The application of such measurements may facilitate the early identification of scapular dyskinesis and contribute to the decisions regarding rehabilitation and sports participation. The main advantage of the study is the investigation of a single sensor-based system that is able to record scapular motion in different directions. The display of both inter-rater and intra-rater reliability offers an unambiguous indication of measurement reproducibility.

Ethical Considerations

The research was conducted in compliance with the ethical principles by Institutional Ethics Committee.

Informed Consent to participate

Before taking part, everyone gave their written consent. They were told what the study was about, how it would work, and any risks or discomforts that might come up. People could choose to participate or not, and they could leave at any time without any problems.

Declaration of conflict of interest

No conflict of interest

Consent for publication

Written informed consent for publication was obtained from all participants

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Data availability

The data that support the conclusions of this study can be obtained from the corresponding author upon a request.

Author contributions

Author 1: Idea generation, research plan, collecting data, processing of the data, analysing the findings and writing the manuscript

Author 2: Giving methodological advice, interpreting data, critically reviewing the manuscript, and giving final approval for the version to be published.

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