Can shoulder impairments be classified from three-dimensional kinematics using inertial sensors?

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Abstract

Inertial sensors may help clinicians to assess patients' movement and potentially support clinical decision-making. Our aim was to determine whether range of shoulder motion during movement tasks measured using inertial sensors are capable of accurately discriminating between patients with different shoulder problems. Inertial sensors were used to measure three-dimensional shoulder motion during six tasks of 37 patients on the waiting list for shoulder surgery. Discriminant function analysis was used to identify whether the range of motion of different tasks could classify patients with different shoulder problems. The discriminant function analysis could correctly classify 91.9% of patients into one of the three diagnostic groups based. The tasks that associated a patient with a particular diagnostic group were: subacromial decompression: abduction; rotator cuff repair with tears ≤5 cm: flexion and rotator cuff repair with tears > 5 cm: combing hair, abduction and horizontal abduction-adduction. The discriminant function analysis showed that range of motion measured by inertial sensors can correctly classify patients and could be used as a screening tool to support surgery planning.

Keywords: Inertial sensors, shoulder, rotator cuff, discriminant function analysis

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Introduction

Treatments for shoulder problems include physiotherapy, injections and surgery.[1] To help with clinical decision-making, imaging examinations are often used to confirm diagnosis and treatment planning. Both Ultrasound Imaging (USI) and Magnetic Resonance Imaging (MRI) are used in the detection of various problems, including rotator cuff tears. A Cochrane systematic review reported that there were no differences in sensitivity and specificity between MRI and USI for detecting full- or partial-thickness rotator cuff tears.[2] Imaging such as Magnetic Resonance Imaging (MRI), can be costly and if there is great demand, may delay treatment.[3] During clinical examination, the use of a screening tool that accurately identifies cases where imaging is required for surgical planning could potentially help to reduce waiting lists for imaging procedures. Three-dimensional motion analysis using inertial sensors has been shown to be able to aid clinicians in identifying altered movement patterns in patients with shoulder problems.[4] Inertial sensors are a relatively new tool that can be used in the clinical setting due to their good ecological validity.[3] Thus, they have potential to be used as an alternative to imaging.[5,6] Other studies have used inertial sensors to compare movement patterns of patients with various shoulder disorders though they only assessed single-plane movements in unloaded conditions.[7-9] For example, Roldán-Jiménez, Cuesta-Vargas, Martín [9] used inertial sensors to investigate which kinematic variable had best diagnostic accuracy to identify shoulder problems; however, only the scaption movement was assessed. The aim of this study was to determine whether measuring range of shoulder motion (ROM) during common clinical and daily tasks using inertial sensors is capable of accurately discriminating patients with various degrees of rotator cuff tendon problems.

Method

We recruited patients aged between 40 and 70 years old, which is the usual age range for patients with symptomatic rotator cuff tears,[10] who were on the waiting list for shoulder surgery in a single hospital. Patients were classified into one of three groups according to the surgery they were listed for: subacromial decompression (SAD), rotator cuff repair with tears of up to 5 cm (RCR ≤ 5cm), and tears greater than 5 cm (RCR > 5cm). Size and classification of the rotator cuff tear was determined by the attending clinician using MRI or USI according to local clinical pathways and clinician preference. We excluded patients who had had previous shoulder surgery and/or other musculoskeletal impairment in the assessed limb or cervical and thoracic spine, people who were unable to understand instructions or non-English speakers. This study received ethical approval (University of Central Lancashire STEMH 462).

Each patient performed five repetitions of six tasks, while standing, in a randomised order:[7,11,12]

1) Combing hair: simulated combing movements taking the hand from the front to the back of the head.
2) Abduction: Maximum abduction in the coronal plane.
3) Horizontal abduction-adduction: horizontal shoulder abduction and adduction holding a 1kg dumbbell with the elbow in extension.
4) Reaching behind back: the participants tried to reach their opposite back pocket.
5) Flexion-extension: maximal forward flexion and extension in the sagittal plane.
6) Lifting: with the arm resting beside their body, the participant raised a 1kg dumbbell to the highest point above their head.

These tasks were chosen based on what is generally used during routine clinical assessments and common tasks used in everyday life that were assessed in similar studies.[11,13] The Xsens/MVN system (Xsens Tech®, Enschede, Netherlands) was used to collect 3D movements of the shoulder at 120 Hz. The manufacturer has reported that pitch and roll was accurate to <0.5º and yaw was accurate to 1º, and confirmed by independent research [14]. All sensors were attached to the patient's body with Velcro® strips over their clothes (Figure 1). The sensor placement, body acquisition configuration (upper body) and calibration procedures followed the recommendations from the equipment manual.[15] For each task, ROM was calculated by subtracting the glenohumeral joint angle at the final position of the task from the glenohumeral joint angle at the initial position of the task.

Insert Figure 1 about here

Mean and standard deviation of the ROM was calculated for each task. Discriminant function analysis using the Wilk's Lambda method was used to identify which of the tasks would be able to discriminate between the three groups, SAD, RCR ≤ 5cm and RCR > 5cm using cut-off points from the function at group centroids. Those tasks whose standardized canonical discriminant function coefficients were greater than the cut-off points were selected to discriminate between the three groups. The matrices of homogeneity were tested using Box's M test, and a classificatory analysis and cross-validation was used to check allocation accuracy for the discriminant function analysis.[16 17]

Results

Thirty-seven patients were recruited. The descriptive data for each task and surgical group is detailed in Table 1.

Table 1. Mean and standard deviation of the ROM of each task for each surgical group (discriminant tasks for each group are in bold).

Task (degrees)	Subacromial decompression (n=15) $\bar{x}$ (SD)	Rotator cuff tears ≤ 5 cm (n=18) $\bar{x}$ (SD)	Rotator cuff tears > 5 cm (n=4) $\bar{x}$ (SD)
Combing	113.02 (8.73)	84.73 (24.19)	**73.67 (23.83)**
Abduction	**110.03 (23.09)**	72.23 (34.40)	**75.01 (40.56)**
Horizontal abduction-adduction	73.08 (14.59)	51.41 (25.27)	**45.56 (31.0)**
Reaching behind back	-19.94 (5.37)	-21.47 (6.08)	-17.80 (4.26)
Flexion-extension	125.65 (22.09)	**115.31 (36.08)**	83.62 (36.53)
Lifting	116.76 (33.78)	103.20 (37.25)	77.99 (39.73)

The first function was chosen as the best to discriminate groups based on its capacity to explain the percentage of variance and the high canonical correlation value (0.854). The test of function indicated an ability to significantly discriminate groups (Wilks Lambda: 0.196, Chi-square 51.4, $P<0.001$). The function at group centroid cut-off points were; -1.580, 0.587 and 1.740 for the RCR ≤ 5, RCR > 5 and SAD groups, respectively.

The standardized canonical discriminant function coefficients used to select the discriminant variables for each group are detailed in Table 2.

Table 2. Standardized canonical discriminant function coefficients and the associated surgical group for each task.

	Function		
	1	2	Associated group for each task
Combing	1.062	0.799	RCR>5cm
Abduction	1.775	-0.794	RCR>5cm / SAD
Horizontal abduction-adduction	0.689	0.001	RCR>5cm
Reaching behind back	-0.514	-0.199	------------
Flexion-extension	-3.033	1.025	RCR≤5cm
Lifting	0.084	-0.263	------------

SAD: subacromial decompression. RCR: rotator cuff repairs.

The Function at Group Centroids were 1.740 for SAD, -1.580 for RCR ≤ 5, and 0.587 for RCR > 5. The values of Function 1 were chosen if they exceeded the threshold value for a specific group

The discriminant variables for each group were, SAD: abduction, RCR ≤ 5 cm: flexion-extension and RCR > 5 cm: combing, abduction and horizontal abduction-adduction. Based on these discriminant variables the classificatory analysis could correctly classify 91.9% of the individuals, while the cross-validated analysis showed an accuracy of 75.7% (Table 3).

Table 3. Classificatory and cross-validation analyses.

			Predicted Group Membership			
			SAD	RCR≤5cm	RCR>5cm	Total
Classificatory [a]	Count	SAD	15	0	0	15
		RCR≤ 5	1	16	1	18
		RCR>5	1	0	3	4
	%	SAD	100.0	0	0	100.0
		RCR≤ 5	5.6	88.9	5.6	100.0
		RCR>5	25.0	0	75.0	100.0
Cross-validated [b]	Count	SAD	13	1	1	15
		RCR≤ 5	2	14	2	18
		RCR>5	2	1	1	4
	%	SAD	86.7	6.7	6.7	100.0
		RCR≤ 5	11.1	77.8	11.1	100.0
		RCR>5	50.0	25.0	25.0	100.0

SAD: subacromial decompression. RCR: rotator cuff repairs
[a]. 34 out of 37 (91.9%) of original grouped cases correctly classified.

[b]. Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.

Discussion

Our aim was to investigate whether the measurement of shoulder ROM during six tasks using 3D kinematics could accurately classify patients according to their shoulder problems.

Classificatory accuracy of the kinematic data from inertial sensors was compared to the imaging results prior to listing for surgery, whether that was USI or MRI. However, as MRI and USI have similar sensitivity and specificity for detecting full- or partial-thickness rotator cuff tears this wasn't thought to affect the comparisons. Almost 92% of the cases were correctly classified and cross-validation confirmed the discriminant capacity of the assessment protocol using the four discriminant tasks: abduction, flexion, combing hair and horizontal abduction-adduction. These values are high and substantially greater than a classification by chance, which in this analysis of three groups would be 33.33%. Successful classifications should be above 80%;[18] the classificatory analysis fulfilled this criteria, but the cross-validation, which checks the discriminant function analysis accuracy case-by-case, was just under that threshold. One possible reason for the cross-validation not reaching at least 80% might be due to the low number of patients in the RCR>5 group.

The discriminant function analysis showed great applicability for the use of inertial sensors when assessing four tasks which could be used to classify patients based on their shoulder ROM. To the authors' best of knowledge, the only other study that has used discriminant function analysis to classify patients with shoulder disorders was Colliver, Wang, Joss, Ebert, Koh, Breidahl, Ackland [19], In their study, discriminant function analysis was used to determine whether surgical repair integrity could be determined by the results of clinical questionnaires. Their results showed that questionnaires could only classify 36% of the intact repairs. The low accuracy may be attributed to using a generic upper limb questionnaire, the QuickDASH instead of a specific questionnaire for shoulder problems. Roldán-Jiménez, Cuesta-Vargas, Martín [9] investigated the discriminating precision of inertial sensors during scaption. They assessed people with no shoulder complaints compared to a group of patients with various shoulder problems. They found that scapular protraction-retraction ROM had 83.3% specificity and 90.9% specificity to diagnose shoulder problems. However, their study only investigated one task and did not try to differentiate shoulder problems; only differences between people with affected and unaffected shoulders.

Similar to our study, Kolk, Henseler, de Witte, van Zwet, van der Zwaal, Visser, Nagels, Nelissen, de Groot [7] performed an analysis where inertial sensors were used to assess movement differences between patients with shoulder pain but no anatomical alterations to cuff muscles or tendons, an isolated supraspinatus tear, or a massive rotator cuff tear of greater than 5cm. They found that patients with a massive rotator cuff tear had a greater reduction in flexion and abduction compared to the other two groups. However, they did not find any group differences in movement in patients with either shoulder pain or an isolated supraspinatus tear. In contrast, we found that patients undergoing subacromial decompression had better ROM than those with a tear smaller than 5 cm; however, our RCR≤ 5 cm group included patients with tears spanning beyond the supraspinatus tendon only.

Using inertial sensors to classify shoulder disorders based on four movement tasks has potential to be used as a screening tool to accurately identify which patients require further imaging when classified into one of the three surgical groups assessed in our study. In the future, it may be possible to incorporate such analysis within smartphones or wearable sensors, allowing access to initial diagnostic assessments. However, further studies are needed to prove its diagnostic capacity.

As this paper looked at the allocation accuracy of the discriminant function analysis only, further work is needed to prove its diagnostic capacity to fully establish the sensitivity and specificity of inertial sensors as a diagnostic tool. Further studies could investigate the accuracy of smartphone or other cheap wearable sensors with the Xsens system used in this study. Other studies could focus on including inertial sensor data from the four movement tasks alongside MRI or USI to improve diagnosis and surgical decision making. A limitation of our study was to look at only one kinematic variable, ROM, and the glenohumeral joint. Future studies should investigate scapular movements and other kinematic variables such as acceleration and velocity.

The use of inertial sensors to assess shoulder ROM appear to be a valuable tool to accurately classify patients with different shoulder problems. The tasks that associated a patient with a particular diagnostic group were: subacromial decompression, abduction; rotator cuff repair with tears $\leq$5 cm, flexion; and rotator cuff repair with tears > 5 cm, combing hair, abduction and horizontal abduction-adduction.

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Figure caption

Figure 1. Xsens sensors placement, A) front view, B) back view