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ABSTRACT

Background: Magnetic Resonance Imaging and ultrasound imaging are often used for clinical decision making to confirm diagnosis and plan treatment in shoulder problems, but this can be costly and reporting the findings can take time. The 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.

Methods: Inertial sensors were used to measure three-dimensional shoulder motion during six tasks of 37 patients on the waiting list for shoulder surgery. Discriminant analysis was used to identify whether the range of motion of different tasks could classify patients with different shoulder problems.

Results: The discriminant 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.

Conclusions: The discriminant 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 analysis

1. 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 Scanning (USS) and Magnetic Resonance Imaging (MRI) are used in the detection of rotator cuff tears. A Cochrane systematic review reported that there were no differences in sensitivity and specificity between MRI and USS 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 help reduce overall costs and 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 easily used in the clinical setting due to their good ecological validity.[3] Thus, they have potential to be used as an alternative to more expensive or less accurate methods of identifying the underlying causes of shoulder pain.[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.[7,8] It is also unknown whether inertial sensors can accurately classify patients with different types of shoulder problems using kinematic variables. 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.

2. METHOD

2.1Participants

Patients aged between 40 and 70 years old, who were on the waiting list for shoulder surgery in a single hospital were recruited. 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 using MRI or USS 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).

2.2 Procedures

Each patient performed five repetitions of six tasks in a randomised order (Table 1).

Table 1. Description of the movement tasks. [7,9,10]

Task	Description
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.

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 [11]. 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.[12] 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

2.3 Statistics

Mean and standard deviation of the ROM was calculated for each task. Discriminant 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 analysis.[13] [14]

3. RESULTS

Thirty-seven patients were recruited. The descriptive data for each task and surgical group is detailed in Table 2.

Table 2. 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 (Table 3).

Table 3. Function at Group Centroid Values.

Function at group centroids		
	Function	
Group	1	2
Subacromial decompression	1.740	0.294
Rotator cuff tears ≤ 5 cm	-1.580	0.130
Rotator cuff tears > 5 cm	0.587	-1.688

The standardized canonical discriminant function coefficients used to select the discriminant variables for each group are detailed in Table 4.

Table 4. 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 5).

Table 5. 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.

4. DISCUSSION

The objective of this study was to investigate whether the measurement of shoulder ROM during six tasks using 3D kinematics could accurately classify patients according to their shoulder problems. Generally, discriminant analyses have been used to identify talents in sports and to select which variables are best to classify subjects to groups.[13,15]

Classificatory accuracy was compared to the imaging results prior to listing for surgery, whether that was USS or MRI. However, as MRI and USS have similar sensitivity and specificity for detecting full- or partial-thickness rotator cuff tears this wasn't thought affect the results. 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 3 groups would be 33.33%. Successful classifications should be above 80%;[15] the classificatory analysis fulfilled this criteria, but the cross-validation, which checks the discriminant 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 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. The only other study that has used discriminant analysis to classify patients with shoulder disorders was Colliver, Wang, Joss, et al. [16] who used discriminant analysis to determine whether surgical repair integrity could be classified by clinical questionnaires. Their results showed that questionnaires could only classify 36% of the intact repairs.

Similar to our study, Kolk, Henseler, de Witte, et al. [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 the potential to be of great clinical use as a screening tool to accurately identlfy which patients require further imaging when classified into one of the three surgical groups. It may be possible to incorporate such analysis within smartphones or wearable sensors, allowing access to initial diagnostic assessments thus relieving pressure on MRI based diagnostic workflows, as waits for the result of this form of investigation can be longer than six weeks in many cases [17], and reducing the cost burden, as for example each shoulder MRI costs approximately £200 [18].

As this paper looked at the allocation accuracy of the discriminant analysis only, further work is needed to fully establish the sensitivity and specificity of this classification system using inertial sensors as well as comparing 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 ultrasound imaging to improve diagnosis and surgical decision making.

5. CONCLUSION

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 ≤5 cm, flexion; and rotator cuff repair with tears > 5 cm, combing hair, abduction and horizontal abduction-adduction. These have the potential to offer a quick assessment which could be performed by clinicians and may allow faster clinical decision making.

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A B

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