CASE REPORT

Robotic Assessment of Upper Limb Function after Proximal Humeral Fracture: Personal Experience as A Patient and Occupational Therapist

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(Received for publication on April 16, 2015)

(Revised for publication on November 30, 2015)

(Accepted for publication on December 21, 2015)

(Published online in advance on September 25, 2016)

Robotics is an emerging field in rehabilitation medicine. Robots have the potential to complement traditional clinical assessments because they can measure functions more precisely and quantitatively than current clinical assessments. We present a patient with a proximal humeral fracture whose recovery process was evaluated with an exoskeleton robotic device. The patient, a 34-year-old woman, suffered a left proximal humeral fracture while snowboarding. She is an occupational therapist and is the first author of this study. With conservative therapy, fracture union was seen on X-ray at 6 weeks post-injury. At that time, the patient was permitted to move her left upper limb actively within the tolerance of pain. We assessed the function of the injured upper limb at 6, 7, and 12 weeks post-injury with the KINARM exoskeleton robotic device and with conventional clinical measures. The active range of motion and the muscle strength of the left shoulder improved over time. Using robotic assessment, the precise movement profiles, position sense, and functional ability of both arms were quantified and also showed progressive improvement over time. Assessment with a robotic device of the recovery process after proximal humeral fracture allowed quantification of functional impairments that could not be felt subjectively nor identified with conventional clinical assessments. (doi: 10.2302/kjm.2015-0006-CR) ; Keio J Med 65 (3) : 57–63, September 2016)

Keywords: robotics, motor skills, quantitative evaluation, upper extremity

Introduction

Robotics is an emerging field within rehabilitation medicine that has the potential to complement traditional clinical assessments and to provide innovative rehabilitation interventions. Rehabilitation robots incorporate sensors that facilitate accurate measurements of movement kinematics and kinetics that can be used to derive measures related to upper limb movements.¹ It has been reported that robots can evaluate clinical functions more

precisely and quantitatively, and with greater reliability, than ordinary clinical assessments.² Previous attempts to utilize robotic assessment have been reported mainly in stroke patients.^{1,3} Studies involving stroke patients showed that robot-derived measures were well correlated with standard clinical measures¹ and demonstrated greater sensitivity in measuring the recovery³ of patients with stroke. However, there has been no report in which a robot was utilized to evaluate the recovery process chronologically after an upper limb fracture. In this study, the

Fig. 1 X-ray of the left shoulder at 6 weeks post-injury.

recovery process after a proximal humeral fracture was assessed with an exoskeleton robotic device.

Case Presentation

A 34-year-old, right-handed woman suffered a left proximal humeral fracture while snowboarding. She had no particular past medical history and had been working as an occupational therapist for 8 years. The fracture was non-displaced and was treated conservatively. The left upper extremity was fixed in a splint for a week and then fixed with a shoulder bandage in an arm sling. Fracture union was observed on X-ray at 6 weeks post-injury (**Fig. 1**), and the orthopedic surgeon permitted active left upper limb motion from this time. As a rehabilitation program, the patient performed active range-of-motion exercises and used the injured limb in daily activities within her pain tolerance. The functionality of the injured upper limb was evaluated chronologically using clinical assessments and assessments made using an exoskeleton robotic device at 6, 7, and 12 weeks post-injury. The patient is the first author of this study and this case is reported with her consent.

Clinical assessments

A board-certified physiatrist (Y.O.) assessed (1) the left shoulder active range of motion, (2) the left shoulder and elbow muscle strength by manual muscle testing,⁴ and (3) the left grip strength using a Smedley's handgrip dynamometer (Grip D T-2177, Toei Light, Saitama, Japan). **Table 1** shows the results of clinical assessments at 6, 7, and 12 weeks post-injury. All measures improved over time.

Robotic assessments

A bilateral robotic exoskeleton, the KINARM exoskeleton robotic device (BKIN Technologies, Kingston, ON, Canada),⁵ was used for the robotic assessments (**Fig. 2A**). The KINARM exoskeleton robotic device supports the arms, forearms, and hands in an unloaded condition and permits movements in only the horizontal plane. The device has one degree of freedom for each joint (shoulder and elbow), i.e., flexion/extension of the elbow and horizontal adduction/abduction of the shoulder. On a display constructed from an overhead projector, the tips of the participant's index fingers were presented as 1.0-cm-diameter white circles in the horizontal plane above the participant's arms. This allowed the participant to perform various motor tasks while sitting in a straight-backed chair. The KINARM exoskeleton robotic device can run various standard tasks. Among these tasks, we assessed three tasks: the visually guided reaching task, the arm position matching task, and the object hit task.

The visually guided reaching task⁶ quantitatively measures reaching performance (**Fig. 2B**). The participant positions his or her hand on a central target (90° of elbow flexion and 30° of horizontal shoulder adduction) and reaches quickly and accurately to one of the eight peripheral targets located at a distance of 10 cm on the circumference of a circle. Reaching is repeated eight times for each direction, constituting 64 actions in total. Three parameters related to the reaching task were adopted in this study: (1) the movement time; (2) the path length ratio, i.e., the ratio of (a) the distance travelled by the hand between the movement onset and movement offset and (b) the straight line distance between the starting and destination targets; and (3) the maximum hand speed achieved during the task.

The arm position matching task⁷ quantifies position sense (**Fig. 2C**). While the participant's vision is blocked with a shield, one limb is passively moved to one of nine specific points by the robot, and the participant actively moves the other arm to the mirror-matched spatial position. The nine points were the corners, the midpoints of each side, and the center of a 20-cm square; the center of the square was positioned at the same location as the center target in the visually guided reaching task. The displacement between the position of the hand that the

Table 1 Clinical assessments carried out by a physiatrist and robotic assessments carried out using the KINARM exoskeleton robotic device

Clinical assessments			Week		
			6	7	12
Active range of motion (°)	Shoulder flexion	L	40	100	130
	Shoulder abduction	L	40	70	135
	Shoulder extension	L	40	40	50
	Shoulder external rotation	L	20	30	70
	Shoulder horizontal abduction	L	0	5	10
Manual muscle test (0–5)	Shoulder flexion	L	2	3	4
	Elbow flexion	L	4	5	5
Grip strength (kg)		L	14	20	22
Robotic assessments by the KINARM exoskeleton robotic device			Week		
			6	7	12
Visually guided reaching task	Movement time (s)	L	1.53 ^a	1.13	1.13
		R	1.11	1.12	1.14
	Path length ratio	L	1.098	1.098	1.084
		R	1.055	1.043	1.069
	Max speed (cm/s)	L	14.9 ^a	22.2	20.3
		R	19.7	20.5	21.6
Arm position matching task	Contraction/Expansion ratio X	L	0.64	0.77	0.85
	Contraction/Expansion ratio Y	L	1.03	1.00	1.04
	Contraction/Expansion ratio XY	L	0.65	0.76	0.89
Object hit task	Target hits (%)	B	56.0 ^a	75.3	77.3
	Miss bias (cm)	B	1.6	0.3	–7.8
	Hand transition (cm)	B	–6.5 ^a	–4.1	–0.3
	Hand speed (cm/s)	L	31.75	31.10	31.53
		R	32.06	34.36	29.11
	Movement area (cm ²)	L	1160	1132	1244
		R	1587	1203	1227

^a Values outside the typical healthy range as assessed by BKIN Technologies.

L, values for the left (injured) arm; R, values for the right arm; B, values for both arms.

robot moved and the mirrored position of the other hand that the participant moved was measured. The contraction/expansion ratio, e.g., the ratio of the area of the shape traced by the participant compared to the area of the shape traced by the robot, was calculated. In this study, the injured left arm was passively moved by the robot, and the patient actively moved the healthy right arm to the mirror-matched spatial position.

The object hit task⁸ is a bimanual task (**Fig. 2D**). Vir-

tual balls (2 cm in diameter) on a horizontal screen move towards the participant. The participant is instructed to hit all of the balls using 5-cm-wide virtual paddles that appear to be attached to each hand. The balls appear at random from ten different locations (located 8 cm apart), with a total of 30 balls released from each location. The following parameters were evaluated: (1) Targets hit, i.e., the score of the task. (2) The miss bias, i.e., any bias of misses toward one side of the workspace (x direction only,

Fig. 2 (A) KINARM exoskeleton robotic device and schemas of the standard tasks, i.e., (B) the visually guided reaching task, (C) the arm position matching task, and (D) the object hit task (courtesy of BKIN Technologies Ltd., Canada).

bias to the right was taken as positive). The miss bias was calculated as the sum of the number of balls missed from each source location (m) multiplied by the source position in the frontal plane (x) in centimeters divided by the total number of misses ($\text{sum}(mx)/\text{sum}(m)$). (3) The hand transition point, i.e., the point in the x direction where the participant's preference for using one hand over the other switches in the workspace (bias to the right was taken as positive). (4) The mean hand speed throughout the task. (5) The movement area of each hand during the task.

The robotic assessments were successfully completed without any adverse events. In the visually guided reaching test, the trajectories straightened and the velocity profiles sharpened and presented a smoother bell shape at 12 weeks compared with those at 6 weeks, especially in the lower left directions (**Fig. 3**). In the left arm, the longest time required in the reaching task was observed at 6 weeks, and the maximum velocity during the reaching task was the lowest at 6 weeks and improved gradually thereafter (**Table 1**).

In the arm position matching task, the manifestation of the left hand position was compressed in the x direction at 6 weeks (**Fig. 4**). The contraction/expansion ratio was as low as 0.65 at 6 weeks, but had recovered to 0.89 at 12 weeks (**Table 1**). Importantly, the patient was unaware of

the change in position sense until she observed the results after the assessment.

The total scores of the object hit tasks improved from 56.0% to 77.3% between 6 and 12 weeks. The hand speed and the movement area in the left arm and the hand speed in the right arm did not change greatly throughout the assessment period, but the movement area in the right hand was high at 6 weeks (**Table 1**). The miss bias at 6 weeks was 1.6 cm to the right and progressed to 7.8 cm to the left at 12 weeks. The hand transition point was 6.5 cm to the left at 6 weeks, but it had moved almost to the center at 12 weeks (**Table 1** and **Fig. 5**).

Discussion

The recovery process after a proximal humeral fracture was assessed using a KINARM exoskeleton robotic device. The precise movement profiles, position sense, and functional ability of both arms were evaluated objectively and quantitatively. We could not assess these aspects of function using conventional clinical evaluations alone. Therefore, the combination of these robotic assessments and conventional clinical scales could expand the scope of assessments and might shed light on new aspects of functional outcomes and thereby inform new rehabilita-

Fig. 3 The trajectory and velocity profiles at (A) 6 and (B) 12 weeks in the visually guided reaching task.

Fig. 4 The arm position matching task at (A) 6 and (B) 12 weeks.

The solid lines to the left of each figure part represent lines connecting the positions to which the injured left hand was passively moved by the robot. The solid lines to the right of each figure part represent lines connecting the positions to which the patient actively moved the healthy right hand as the mirror-matched spatial positions of the perceived left hand. The dotted lines give the mirror image of the right hand's trace to compare the actual positions of the left hand made by the robot and their perceived positions (manifested by the right hand).

tion approaches.

Particularly interesting findings were obtained in the robotic assessments of position sense and the functional ability of both arms. In the arm position matching task carried out at 6 weeks, the position sense of the injured limb (which had been fixed for 5 weeks) was distorted and shrunken. In the object hit task, the miss bias, or the distribution of missed balls in the workspace, deviated slightly to the right at week 6, but at 12 weeks the miss

bias deviated to the left; the hand transition point deviated to the left at 6 weeks, but at 12 weeks, the hand transition point was almost central. These findings indicated that there was likely an overcompensation by the healthy right arm to cover the injured left side, and this seemed to be one of the factors that reduced the total score at 6 weeks. Langer et al. examined ten right-handed subjects with injury of the right upper extremity that required at least 14 days of limb immobilization.⁹ After immobilization,

Fig. 5 The object hit task at (A) 6 and (B) 12 weeks.

The horizontal scale shows the workspace location in the x direction. The balls hit in each position are represented by gray (right arm) or black (left arm) rectangles. Misses are represented by white rectangles. The results descend from the top to the bottom as time progresses. There are more blanks, representing misses, in the lower part of the figure because the speed and the number of balls presented gradually increase with time. At 6 weeks, there were many misses by the healthy right arm in the right side of the workspace. This is because the hand transition point was displaced to the left as a compensatory measure, resulting in the right hand sometimes being out of position to hit balls far to the right.

magnetic resonance imaging scans revealed a decrease in cortical thickness in the left primary motor and somatosensory areas of the brain and a decrease in fractional anisotropy (FA) in the left corticospinal tract. In addition, the motor skill of the left (noninjured) hand improved and was related to increased cortical thickness and FA in the right motor cortex. The shrunken perceived limb position of the injured left arm and overcompensatory use of the noninjured right arm after immobilization in our study were consistent with their findings. Furthermore, the perceived limb position was mainly decreased in the x direction. The horizontal hand position in the x direction was mainly determined by the injured shoulder angle, while the position in the y direction was determined mainly by the elbow angle. We speculated that the x-direction-specific changes in the perceived limb position might result from this kinematic property. Interestingly, the patient was completely unaware of these functional changes or behaviors in the task until observing the results of the robotic assessments. Robotic assessments can highlight new aspects of functional impairments that cannot be subjectively observed, even by a professional.

There are some limitations in this study. First, the generalizability of the results is limited because this is a single case report. Second, we did not perform clinical assessment of the position sense. Therefore, we could not compare the utility of the robotic assessment with the conventional clinical assessment for position sense. Third, the findings of the KINARM exoskeleton robotic device cannot be simply applied to real world situations because all robotic assessment tasks were executed on the horizontal plane with gravity support. Consequently, gravity

support could reduce the detectability of abnormal function. The data from the KINARM device were within the typical range of healthy people at week 7, whereas the clinical assessment data were not. In the future, we need to explore how to properly use these two types of assessments, i.e., robotic assessment and conventional clinical scales, for clinical decision making.¹

Acknowledgments

This study was supported in part by collaborative research funds from Toyota Tsusyo Corporation.

Conflict of Interest

The authors declare no conflicts of interests.

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