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Developing a Comprehensive Rehabilitation Evaluation System for the Minimization of Reinjury in Postoperative Rotator Cuff Pendulum Exercises

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***Abstract*—**Pendulum exercises are commonly used in early stage of rehabilitation exercises after rotator cuff repair. However, strain or micromotion at the repair site should be avoided during this phase to facilitate healing. We hypothesized that patients who performed pendulum exercises with improper motion after surgery would increase the potential for recurring injuries. To minimize such injuries and to monitor improper movement, a real-time monitor and warning system that evaluates motion of pendulum exercises was developed. The subjects of study were homogeneous in age and fatty grade, tear size and location, and surgical technique. After initial assessments were performed, the group with the real-time warning system obtained prominent vascular findings at the adjacent repair site after one week ($p<0.001$), and resulted in lower re-tear rates ($p=0.013$) twelve weeks after surgery, compared to the group without a real-time warning system. Use of an accelerometer to monitor backward shoulder movement was successful in facilitating tendon-to-bone vascular response and preventing a higher re-tear rate. The comprehensive rehabilitation evaluation system appeared to be effective in minimizing re-injury in the early stages of rehabilitation after rotator cuff repair by monitoring improper shoulder movement through a real-time warning system.

***Keywords*—**Accelerometer; Rotator cuff repair;Pendulum exercises; Ultrasound ; Digitial imaging processing

I. INTRODUCTION

Rotator-cuff specific exercises [1] in early rehabilitation after rotator cuff repair have been controversial. Typically, within a day of surgery, surgeons allow patients to begin gentle passive motion as well as gentle circle pendulum exercises (as developed by Codman [1] in 1934). However, re-tearing rates of 25% to 94% have been reported [2] in the literature for rotator cuff repairs. Strain or micromotion at the repair site should be avoided during this phase to facilitate healing. Identifying how to improve postoperative tissue healing should be a priority [3].

It has been shown in literature that more intense activities of daily living (ADL), such as a backwards pulling or shoulder shrug, compensate for motion early in rehabilitation after rotator cuff repair [4][5]. Little was known about the shoulder-shrug habits, hence little could be done for real-time improvement to avoid backward pulling motion in the postoperative patient during activities of daily living and in pendulum exercises. Pendulum exercises should not exceed 20cm in motion, as shown by Long et al [7].

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To our knowledge, Codman's exercises protocol utilizes the concept of a very complex nature of shoulder joints, which makes equal pendulum motion possible. Recently, due to the compact size and inexpensive price of the accelerometer, it has been recognized as a useful device to measure the stereometry of physiotherapy. Kavanagh et al. [7] reported that accelerometers are sufficiently sensitive to detect rapid movements, such as physiological or pathological tremors.

Both animal studies by Peltz et al. [8] and Uhthoff et al. [9] demonstrated that immobilization for at least 2 weeks post-operation is critical to the process of tissue healing. This is because revascularization plays a critical role in the healing process of tendon-to-bone insertions; they help bridge the gap between tendon and bones, facilitating healing [1]. Restoring repair tissue revascularizations can be efficiently achieved with a comprehensive rehabilitation evaluation to prevent physiological tremors in order to contribute to the healing in early rehabilitation after rotator cuff repair [10].

We hypothesized that reduction of backward shoulder movement should prevent cuff re-tear and facilitate tendon-to-bone vascular response. Patients performing pendulum exercises with the backward shrug movement after rotator cuff repair would increase the potential of recurring injuries. Therefore, developing a valid real-time accelerometer was required for the postoperative pendulum exercises in order to reduce shoulder-shrug habits.

II. METHOD

In order to evaluate the pendulum exercises with backward shrug movement that may be associated with revascularizations at the 2nd week after rotator cuff repair, the graphics of rehabilitation evaluation would be developed to detect the movement. Through the accelerometer and digital image processing the clinical study hopes to visualize the backward shrug movement and monitor revascularization.

A. Acceleration monitors developing methodology

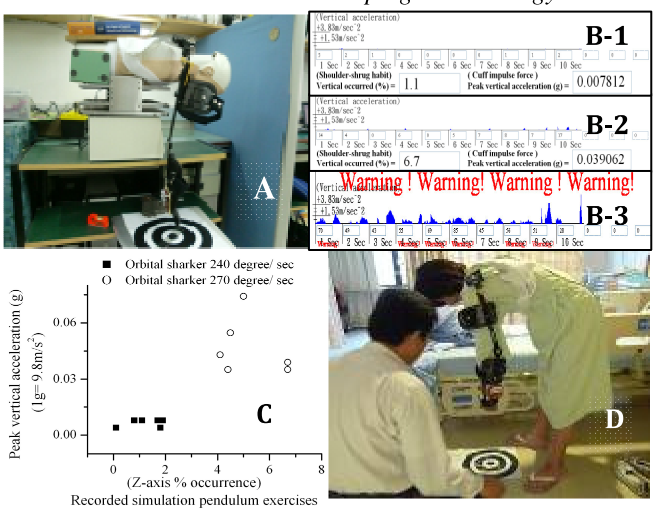

Figure 1. The figures represent architecture of rehabilitation evaluation system in the Codman's protocol. (A) Orbital shaker simulates the pendulum exercises. Display of the pendulum exercise acceleration data: Angular speed of pendulum obtained by the orbital shaker operating at (B-1) 240 deg/sec, (B-2) 270 deg/sec, and (B-3) the computer screen displays a "Warning" alert each time the vertical acceleration occurrence ratio surpasses 50% and the peak vertical acceleration surpasses 1.96 meter/sec^2. (C) By simulations it was seen that the increase of the angular velocity of the orbital shaker (from 240 deg/sec to 270 deg/sec) resulted in the increase of the vertical acceleration occurrence ratio and peak vertical acceleration by 5 times. (D) The patient performing pendulum motion exercise.

The monitoring device was designed using an accelerometer (Analog Devices ADXL-345, range: ± 2g) as the key component to measure accelerations during pendulum exercises. The accelerometer will be sensing motion signals in the x-, y-, and z-axis directions with 10 bits resolution. However, for the system consideration, the designed system output 8 bits data for each axis. During the pendulum exercises, data was recorded at 100 Hz. The recording system and user interface function was shown in Figure 1, B panel. Within the pendulum exercises, when tremors has movement in the vertical (z) direction, the recording will display blue-color waves (wave amplitude as a z-axis magnitude of acceleration) on the base line as shown in Figure 1, B panel as in B-3 figure. The occurrence of vertical motion in each second will be recorded and shown as percentage of Z motion occurrence. The vertical motion occurrence that surpassed 50% recording will be assumed that patient has shoulder-shrug habit. The peak vertical acceleration in each trial will be recorded in every five seconds. If the peak vertical acceleration was greater than 1.96 meter/sec^2, the system would display a big "Warning" alert signs.

As shown in Figure 1, panel A, an orbital shaker (controlled to generate 25-mm diameter circumference orbital motion) simulated circular motions of body-trunk to swing an arm support brace. The characteristics of the humeral joints and bone are asymmetrical when performing pendulum exercises; larger pendulum circumference will produce as physiological or pathological tremors. The arm support brace was also asymmetrical, in order to simulate the pendulum exercises related to the variable angular swings produced by normal arm motions. It was observed that when the angular speed of the orbital shaker was slower than 240 deg/sec (close to 1.5 s per circle), the magnitude of the diameter for the pendulum motion was smaller than 20 cm; however, when the angular speed of the orbital shaker was greater than 270 deg/sec, the diameter would increase sharply beyond 51 cm. Recorded simulation pendulum exercises, when the angular speed of the orbital shaker was slower than 240 deg/sec, there were very small magnitudes of the vertical acceleration occurrence ratio, and related to the peak vertical acceleration. When the angular speed of the orbital shaker was greater than 270 deg/sec, the results of recorded the larger diameter pendulum will produce to increase the magnitude of the vertical acceleration and high percentage of z-motion occurrence, and as become visible by the peak vertical acceleration increased.

B. Digital image processing

This study will compare the vascular response at the tendon-to-bone interface after the first week of bedside rehabilitation exercise. The study was prospective and double-blinded. Both the physicians (including surgeon, radiologist and physical therapist) and the patients were blinded to the results of their postoperative ultrasound findings. To resolve the subjective patients' vascular response scoring system, High-resolution sonography was used to perform the image-taking using a linear transducer (L12-5, phased-array transducer) and an IU22 scanner (both devices were provided by Philips Medical, Bothell, Washington, USA). Color Doppler scans were obtained by using the same setup from affected arm placed by using musculoskeletal superficial mode with low-flow sensitivity settings. To allow for simultaneous visualization of the supraspinatus tendon, each image was obtained along with the supraspinatus tendon, the myotendinous junction, insertional footprint, suture anchor site, and peribursal tissues [11]. To assess the supraspinatus, the patient was in a seat-down position with the affected arm placed in mild internal rotation and extension, as tolerated by the patient, as shown in Fig 2.

Figure 2. (A) Each Doppler sonography (with specific scanning mode and settings) was obtained by using the same setup for affected arm placement. (B) The images present two regions of interest (peri-bursal, and tendon adjacent to the repair site). By Doppler sonography, vascular particle number and area pixels count were obtained from Image J software.

Conventionally, subjective scoring system was employed to assess blood flow in the region as being absent (0), sparse (1), moderate (2), or prominent (3)[13]. Alternatively, the degree of vascularity was categorized as none (no vessels seen), mild (< 2 vessels seen in the tendon), moderate (2-5 vessels), or good (> 5 vessels) [14]. The Doppler flow measurements are interlaced with the anatomical B-mode images to form duplex images, also known as power Doppler or color flow images.

Image J software was employed to quantify blood flow. The functions of Image J software were employed to convert RGB colors (red, green, blue) to HSB (hue, saturation, brightness) where the color information had been employed in the computation of vascular pattern analysis. To evaluate the vascular particle count the commands of Image J were analyzed after segmentation. The vascularity data was recorded at vascular particles and area of pixels count in the two regions of interest (peribursal, and tendon adjacent to the repair site), as shown in Fig 2.

C. Clinical study procedure

Approval was obtained from the Institutional Review Board, Cheng-Shin General Hospital, Taipei, Taiwan. Between February 2012 and September 2013, 28 cuff mini-open double-row repairs were performed at our institution. The letter of clinical trial consent was signed. For both patient groups, we recorded the initial assessment (UCLA, ASES, DASH) [16] for functional measurements. All patients had diagnostic evidence of a supraspinatus tear (identified with MRI) to meet the strict inclusion criteria of a homogenous group of patients to examine. However, the tear size might be extended by up to 1 cm after debridement of the degenerated tendon edges.

Inclusion criteria included: (1) an isolated full-thickness crescent shaped supraspinatus tear repaired using a mini-open anchor suture techniques previously described; (2) an ultrasound examination to assess the suture without loose fixation at least 9 days after surgery; and (3) at least 3 months of the surgeon follow-up healing rate (by MRI [12]). Exclusion criteria included (1) any previous shoulder injuries (includes revision rotator cuff repairs or arthritis) performed along with the rotator cuff repair; (2) tears that had an L-shaped pattern [13], repaired along the longitudinal split, or tears that extended into the subscapularis or the infraspinatus; (3) evidence of referred pain to the shoulder from other reasons; (4) accompanying infection at the time of repair; (5) worker's compensation cases.

A simple randomization technique was used in a random-number table. The odd-numbered group utilized the rehabilitation evaluation system with a warning system implemented, while the even-numbered group collected only data, without warning system. In both groups, physiotherapists would supervise the patients in their exercises. All physiotherapists who provided treatment to subjects participating in the study were instructed in these protocols to ensure that the initial bedside rehabilitation with protocol guidelines was standardized. All patients were instructed to attend the initial standardized bedside rehabilitation and perform limited pendulum exercises with devices (Fig. 1D) within 6 days after surgery. The group with the evaluation system with the warning system relied on the warning system to notify the patient and therapist of improper shoulder movement. The other group without the warning system relied only on the supervision of the therapist during the exercises.

Real-time warning system procedure which was applied to the patients incorporated the experience learned from a demo picture taken from the laboratory simulation. The patients used the real-time warning system to perform small pendulum-motion exercises at a slow pace and to avoid active motion. Therapists instructed patients that the trunk swing period should be kept close to 1.5 s per circle to ensure the maximum diameter for the pendulum motion would be less than 20 cm. The peak vertical acceleration for the trace is displayed in the lower middle side. Physiological tremors would be recorded as peak vertical acceleration surpassed 1.96 meter/sec^2 and the computer screen would display a warning. This warning indicated the existence of a potential healing failure defect due to a tear at the tendon-to-tuberosity interface. Performing pendulum exercises should be done with great caution for each repetition. After viewing the computer images, real-time warning system group patients were made to understand that slower performance and a small pendulum were safer, as an increase in muscle tearing would occur with vertical acceleration.

In the process, the patients performing the pendulum exercises were observed and assessed by the physiotherapists, while the investigators observed and recorded the data. The revascularization adjacent to the repair site was assessed after one week post-rehabilitation. Sonography assessments were required to make sure no loosening of fixation or surgical failure had occurred. Ultrasound images were compiled by two independent reviewers with more than 6 years of experience in ultrasound assessment. At the same time, vascularity of the tendon adjacent to the repair site at the footprint-articular junction was assessed by using high-resolution color Doppler. The ultrasonographer was blinded as to the type of procedure the patient had and the results of prior ultrasound scans.

D. *Clinical outcome efficiency of re-tear (MRI)*

To record and analyze the clinical outcome efficiency of re-tear, magnetic resonance imaging (MRI) measurements for tear size was performed preoperatively and 12 weeks post-surgery. The integrity of rotator cuff repair was assessed by MRI, with the starting point from the footprint (lateral edge of the articular surface) to the transverse dimension of the retracted tendon ends [12]. MRI images were compiled by an independent reviewer with more than 6 years of experience in MRI scan assessment.

E. *Outcome measurement, image analysis and Statistical analysis*

Ultrasound imaging quantification and analysis Image J software (NIH, USA) was used to conduct qualitative and quantitative analysis by focusing on 2 defined areas, including (1) the adjacent repair site within the greater tuberosity, and the (2) peribursal area (Fig. 2). The adjacent repair site encompassed the cortical defect and any region of enhancement immediately contiguous with the defect. The peribursal area was defined as the region of enhancement contiguous with the bursal surface of the supraspinatus tendon, the peribursal fat, and approximately a 1-cm strip of overlying deltoid muscle.

The Image J software permitted analysis of each region of interest by vascular particles and area of pixels count, measured in the color region of vascular pattern analysis, with respect to baseline gray levels.

Table 1: Patients' demographic comparisons between the two groups (Group1: Real-time warning system, Group2: Without real-time warning system) about MRI and functional assessment pre-operation.

Variables	Precondition Group 1	Group 2	*p*
Age	65.5(8.80)	67.5 (9.64)	0.60
Gender (male: female)	4:8	3:9	0.5
Preoperative tear size	2.54 (0.85)	2.60 (1.61)	0.46
Fatty grade	1.42 (1.38)	1.92 (1.64)	0.36
ASES	47.93(13.85)	48.47(15.58)	0.93
UCLA	12.33(4.83)	13.36(3.47)	0.57
DASH	65.62(19.89)	75.05(21.19)	0.51

Note: Mean (SD)

A student *t* test was used to analyze data obtained from accelerometer parameters, vascularity area measurements and re-tear rate outcomes in both groups. The statistical software package used in the evaluation was SPSS (version 17.0; SPSS, Inc., Chicago, IL, USA). It should be noted that for all statistical analyses done in this study, *p* values of <0.05 were considered statistically significant. To identify backward shrug movement variables and tendon-to-bone vascular response at the 2nd week findings, Kendall's Tau-b correlation coefficient analysis was conducted as a preliminary analysis. To identify differences between preoperative characteristics of the two groups, the functional assessment and following data (such as: age, gender, tear-size, and fatty grade) was analyzed by student *t* analysis.

Table 2: Student *t* test and Kendall's tau correlation coefficients for the two patient groups. The vascularity area pixels of the adjacent repair site were used for variables versus analysis for Kendall's tau correlation coefficients.

Variables:	Group with real-time warning system (n=12)	Group without real-time warning system (n=12)	*p*	Kendall's Tau-b analysis coefficient	*p*
Vertical occurrence (%)	23.61(28.81)	78.61(27.71)	<0.001	-.418	0.004
Peak vertical acceleration(g)	0.0384(0.034)	0.265(0.267)	0.008	-0.396	0.007
Efficacy of re-tear rates	0.25 (0.452)	0.75 (0.452)	0.013	-0.421	0.015
Fatty grade	1.42 (1.38)	1.92 (1.64)	0.36	-0.285	0.07
Repair site vascularity area (pixels)	946.8 (465.3)	241.7 (197.8)	<0.001	-	-
Peribursal vascularity area (pixels)	2219.3 (1565.3)	1489.9 (1143.8)	0.204	-	-

III. RESULTS

A. *Preoperative patient demographics*

Of these 28 repair patients, 24 patients (7 men, 17 women) met the inclusion and exclusion criteria and were included in this study and were MRI monitored for at least 3 months postoperatively.

One patient was excluded part way through the study because of pain in the affected side from a cervical surgery prior to RCR, and three patients were excluded because of the lack of MRI assessments 12 weeks post-surgery. Patient ages averaged 65.6 years (range, 45-84 years). There were no significant differences between the two groups prior to operation for any characteristics or preoperative measures and functional assessment listed in Table 1.

And both groups were assessed by sonography one week after their operations to determine the influences from surgical techniques and the first week of bedside rehabilitation exercise. Moreover, both groups also displayed a similar baseline of cuff characteristics (no loosening of fixation).

B. *Results of pendulum exercise with comprehensive rehabilitation evaluation system*

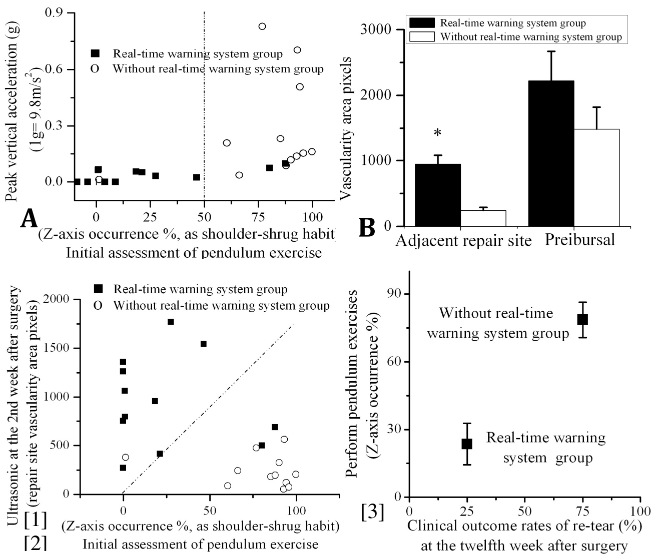

Figure 3. The images illustrate two different patient groups and clinical outcomes. (A) Shoulder shrug habit in the real-time warning system group and the without real-time warning system group. The real-time warning system group had less peak vertical acceleration than the without real-time warning system group. (B) Vascularity areas pixels count of the peribursal and tendon adjacent to the repair site of the two groups. (C) Vascularity area in pixels of the two groups of patients. Patients in the real-time warning system group generally had larger vascularity areas. (D) Re-tear rates of the two groups 12 weeks after surgery.

After rotator cuff repair, in performing pendulum exercises, the warning parameters of peak vertical acceleration and vertical acceleration occurrence ratio (as shoulder-shrug habit) obtained by accelerometer measurements were observed to have a significant reduction ($p < 0.001$) on the group with the warning system. Postoperatively, patients performed pendulum exercises similar to the asymmetric arm support in laboratory tests. By simulations it was determined that increasing the vertical acceleration occurrence ratio (typical of shoulder-shrug habit) was associated with relative amounts of the peak vertical acceleration (as cuff impulse force), as shown in Fig 3 (A). There were two outliers in the real-time warning system group. Both patients had high vertical acceleration occurrence ratio, with corresponding low peak vertical acceleration and low vascularity area pixels adjacent to the repair site. There was also an outlier in the without real-time warning system group, with low vertical acceleration occurrence ratio, but with low vascularity area. In Table 2, the vertical occurrence and peak vertical acceleration were assessed by accelerometer, while re-tear rates and fatty grade were assessed by MRI, and repair site and peribursal vascularity areas were assessed by ultrasound.

To evaluate the effect of revascularizations between two different patient groups at the 2nd week after surgery echo-color-Doppler was used, as shown in Fig 3 (B). Postoperatively, it revealed that the patients in the group with the real-time warning system had more prominent vascular findings at the adjacent repair site ($p < 0.001$), as shown in Table 2 and Fig. 3(C). However, on the peribursal cross-section area, there was no significance noticed between the two groups ($p=0.204$) in terms of vascularity. Overall, the group with the real-time warning system appeared to be effective in facilitating repair by aiding the optimal formation of the tendon insertion and by efficiently preventing re-tear rate ($p =0.013$).

Therefore, the comprehensive rehabilitation evaluation system appeared to indicate that postoperative pendulum exercises that reduced shoulder-shrug habit during the first week following surgery helped in facilitating tendon-to-bone vascular response and the efficiency of preventing cuff re-tear rate.

C. *Rehabilitation evaluation related to revascularizations*

The relationship between the re-tear rate at the twelfth week after surgery, the vascularity adjacent to the repair site, and the vertical acceleration factor was analyzed using Kendall's Tau-b correlation analysis. It was observed that instruction to prevent shoulder-shrug habits improved repair site regions vascularity, as shown in Table 2.

Negative correlations were seen between vertical acceleration and revascularizations adjacent to the repair site ($p<0.01$). In addition, the vascularity adjacent to the repair site also had a negative correlation with cuff re-tear rates (p=0.015) at the twelfth week after surgery.

However, on the overall patients' fatty grade, there was no significant (p=0.07) negative correlation implications to the vascularity adjacent to the repair site at the 2nd week after surgery.

IV. Discussion

Based on the results of this prospective, case-controlled study, it appears that patients performing pendulum exercises with the backward shrug movement after rotator cuff repair would increase the potential of recurring injuries. This study is the first to extensively investigate the relation between the shoulder shrug habit and re-injury, tissue formation and vascular growth. The results are consistent with earlier Gimbel et al. [16] and Soslowsky et al. [3] proposed exercise-based animal model studies that repetitive mechanical loading may result in inflammation and degenerative change through the tissue at the insertion site. At this time, the literature suggests that patients with the impaired tendon at its insertion site and its mechanical properties are very weak; therefore, patients sometimes produce physiological tremors to compensate for their lack of strength, and thus create repeated activation on the repaired muscle, resulting in reinjures. However, patients are usually unaware of such tremors and their negative impact on their injured areas; therefore developing a warning system could be critical for informing the patient of improper shoulder movement.

Assuming shoulder shrug habit can be modeled as passive movement with small pendulums (less than 20 cm in diameter) as proposed by Long et al. [7], this study developed an orbital shaker to simulate pendulum exercises in order to measure vertical acceleration. The arm support brace is designed to simulate the glenohumeral joints of the asymmetric properties; larger pendulum circumference will produce as physiological or pathological tremors. Long et al. proposed through EMG results that the safeties of muscular activation are achieved by maximal voluntary isometric contraction (MVIC) below 15% when performing small pendulum exercise. This 15% MVIC correlates to 30 newton (N) of force, based on in vitro biomechanical testing. In our studies, if the peak vertical acceleration surpassed 1.96 Meter/s^2, the computer screen would display a big “Warning” alert. This was based on the calculation that the average mass of a human arm is 5.4 kg. Multiplying the mass by a vertical acceleration of (9.8+1.96=11.76) meter/sec^2 would result in a force of greater than 50N, which, according to literature, is the lowest force of cyclic loading of the rotator cuff for failure [17] [18].

Previously, the EMG monitoring method proposed by McCann et al. [19] lacked a nonlinear transformation from muscle activation to muscle force and a method for monitoring shoulder shrug habit. Therefore our studies included a warning for the upper limit of safe loading of limited-repetition activities when vertical occurrence acceleration surpasses 50%. In this way, this study used visual and proprioceptive feedback to prevent backward shrug habit with the help of the rehabilitation evaluation system [20], rather than letting patients themselves extrapolate from the complex concept of the passive exercises.

Our results demonstrated that the pendulum exercises performed by the patients were similar to the asymmetric arm support simulations in laboratory tests in that increasing circumference in diameter is associated with larger amount of peak vertical acceleration and subsequently would hinder healing and increase reinjury rates. The without real-time warning system group and the two outliers in the real-time warning system group appeared to support this notion; like the without real-time warning system group, both patients had high vertical acceleration occurrence ratio, with corresponding low peak vertical acceleration and low vascularity area pixels adjacent to the repair site, indicating lesser degree of healing.

In addition to the two outliers in the real-time warning system group, there was an outlier in the without real-time warning system group. This patient had low vertical acceleration occurrence ratio, but because of their lifestyle, healing in the injured area was inhibited and therefore there was low vascularity area in pixels adjacent to the repair site.

Gamradt et al. [1] through quantification of vascular response, demonstrated that the surrounding vascular milieu may play a role following supraspinatus repairs. The system developed in this study demonstrated its viability as statistically significant reduction in shoulder-shrug motions was achieved and vascularity adjacent to the repaired site was prominent one week after rehabilitation. Whilst vascular response adjacent to the repaired site was significantly improved one week after rehabilitation in the real-time warning system group, the immediate post-exercise vascularity results (i.e. on bedside rehabilitation) were not specifically measured and hence, groups may have differed considerably at this time. Even though a true feature color Doppler is limited in sensitivity for detection of flow [21], it can be used for the monitoring of the revascularization of postoperative rotator cuff repair formation. The primary stage of graft vascularization, which occurred in the first two weeks, [8] was to surround the graft material by thick, richly vascularized loose connective tissue. In addition, Galatz et al. [23] studies demonstrated that restoration of the insertion site is critical for the repair of tendon function and to prevent reinjury in the 12 weeks following rehabilitation. It is clear that revascularization of the insertion site is critical for the restoration of tendon function and for the prevention of re-injury.

In this prospective randomized study, we observed that the prominent vascular findings at the adjacent repair site of both patient groups appeared to efficiently prevent re-tear rate at the twelfth week after surgery. The results of this study seem to be consistent with other literature [24]. Our study appears to be successful in supporting our hypothesis of reducing backward shrug movements using a comprehensive rehabilitation evaluation system, resulting in improvement of prevention of re-tear rates. This reduction in the backward shoulder pulling activity was due to the implementation of the warning system, which warned the observer of improper shoulder motion [25].

It should be noted that this study has some limitations. First of all, backward pulling motion in activity of daily living is a continuous risk for postoperative patients after rotator cuff repair and this study only sought to limit backwards pulling motion in the initial rehabilitation period. In addition, the study was done completely under a hospital environment. Therefore, further experimentation should be done in a home environment to ensure results are universal regardless of environment. Secondly, color Doppler image assessing blood flow has subjective qualitative scoring system. There is variability in direction and position for each scan. Because of this, we quantified vascularity features through a subjective scoring system based on vascular particle number and area pixel count. Therefore, further studies could be done to better quantify vascularity features.

V. CONCLUSION

Limiting improper backward shoulder shrug habits in the early stages following rotator cuff repair is crucial in the post-rehabilitation process after rotator cuff surgery. Through real-time warning, the comprehensive rehabilitation evaluation system appeared to be effective in minimizing re-injury in the early stages of rehabilitation after rotator cuff repair by warning the patient of improper shoulder movement when it occurred.

Use of a monitoring accelerometer [27] to prevent backward shoulder movement and facilitate tendon-to-bone vascular response by a real-time warning system resulted in improved efficacy of preventing re-tear rates and improved vascularity in areas adjacent to the repair site. In future studies we hope to develop a system that could be implemented not only in the hospital but daily personal use as well [26].

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