Article

Shoulder musculoskeletal disorder rehabilitation using a robotic device based on EMG biofeedback: a retrospective cohort study

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Abstract: While shoulder injuries represent the musculoskeletal disorders (MSDs) most encountered in physical therapy, there is no consensus on their management. As attempts to provide standardized and personalized treatment, a robotic-assisted device combined with EMG biofeedback specifically dedicated to shoulder MSDs has been developed. The aim of this study was to determine the efficacy of an 8-week rehabilitation program (≈3 sessions a week) using a robotic-assisted device combined with EMG biofeedback (RA-EMG group) in comparison with a conventional program (CONV group) in patients presenting with shoulder MSDs. This study is a retrospective cohort study including data from 2010 to 2013 on patients initially involved in a physical rehabilitation program in a private clinic of Chicoutimi (Canada) for shoulder MSDs. Shoulder flexion strength and range of motion were collected before and after the rehabilitation program. Forty-four patients participated in a conventional program using dumbbell (CONV group) while 72 of them completed a program on robot-assisted device with EMG and

visual biofeedback (RA-EMG group), whereby both programs consisted in 2 sets of 20 repetitions at 60% of maximal capacity. Results showed that the RA-EMG had significantly greater benefits than the Conv group for shoulder flexion strength (+103.1% vs 67%, p = 0.016) and range of motion (+14.4% vs 6.1%, p = 0.046). The current retrospective cohort study showed that a specific and tailored rehabilitation program with constant effort by automatic adjustment of the level of resistance was able to potentiate strength and range of motion shoulder flexion after an 8-week rehabilitation period in comparison with a conventional approach in patients with shoulder MSDs. This study provides new insight on shoulder MSD rehabilitation and future research should be pursued to determine the added potential of this approach for abduction and external rotation with a randomized controlled design.

Keywords: rehabilitation; shoulder; electromyography feedback; visual biofeedback; assistive robot; musculoskeletal disorder

1. Introduction

Shoulder injuries, such as tendinopathies, subacromial pain syndrome and rotator cuff-related shoulder pain [1], represent the most widely encountered musculoskeletal disorders (MSDs) in physical therapy [2]. Physical work condition has been identified as one of the major causes of MSDs [3], especially at the shoulder [2]. While shoulder MSDs result in functional discomfort associated with pain [4,5] and impact quality of life and work productivity [6], management ranging from a surgical approach [7–10] to conservative treatment such as rest period, analgesic and pharmacological therapy, and physical therapy are still debated [11].

To date, surgery does not appear to be more effective than physical therapy for subacromial pain syndrome [7–9,12], and of course, is more invasive and expensive. A recent systematic review and meta-analysis reported that five treatments (acupuncture, exercise, exercise plus manual therapy, laser therapy and TENS) had a high effect size (surface under the cumulative ranking curve values >50%) for management of pain and functional outcomes in subacromial shoulder conditions at short-term follow-up (2-6 weeks) [13]. In addition, exercise therapy has been shown to improve active range of motion, overall shoulder function and pain scores at short and long-term follow-up in patients presenting with subacromial pain syndrome [5,13–18]. Despite these promising benefits, there is no strong evidence to delineate the contour of dose-response efficacy including number of repetitions, frequency and level of effort [19]. Attempting to help clinician for providing a standardized and safe approach, muscle strengthening machines have undergone major technological changes, leading to the appearance of a new generation of machines integrating computerization, automation and robotic assistance.

In this context, robot-assisted training has been developed in neurorehabilitation [21–25]. A meta-analysis by Chen et al. [20] showed that robot-assisted training provided better outcomes for motor impairment disability compared to therapist-assisted training and no inferior outcomes for upper limb capacity, activity of daily living and social participation after stroke. Other studies using robotic-assisted devices for the rehabilitation of humerus [26,27] or radius fractures [27] have shown promising results. So as to reinforce the benefits of a robotic-assisted program for the upper limb [28], electromyography (EMG) activity biofeedback has

been combined to help the patient to reach a target through visual feedback and to adjust the level of assistance [29]. Using robotic-assisted device combined with EMG biofeedback in a 8-week rehabilitation program (3-sessions a week), Bui et al. [30] showed significant improvement in maximal voluntary isometric flexion and abduction contraction of the left and right shoulders in a healthy population (n = 7). A robotic-assisted program combined with the EMG biofeedback approach have yet to be evaluated in rehabilitation of patients presenting with shoulder MSDs.

The objective of this study was to determine the efficacy of an 8-week rehabilitation program using a robotic-assisted device combined with EMG biofeedback (RA-EMG group) in comparison with a conventional program (CONV group) in patients presenting with shoulder MSDs after occupational injury. We hypothesized that robotic-assisted device combined with EMG biofeedback would provide an added value to conventional training programs in patients with MSDs.

2. Materials and Methods

2.1. Participants

This study is a retrospective cohort study including data from 2010 to 2013. Patients were initially involved in a physical rehabilitation program in a private clinic of Chicoutimi (Canada). To be included in this study, the participants had to be a diagnosed with shoulder MSDs (i.e., subacromial pain syndrome, shoulder dislocation, adhesive capsulitis, etc.) following an occupational injury; to be referred by a health professional (medical doctor, orthopedic physician or physiotherapist); to be able to practice physical activities without medical contraindications; to have completed 3 training sessions a week during 8 weeks; to have completed the training with robotic-assisted device combined with EMG-FB (RA-EMG group) or conventional training program (CONV group)(Figure 1). The exclusion criteria were patients with behavioral (cognitive and/or psychiatric) disability. This procedure was approved by the Ethics Committee of research of the University of Quebec in Chicoutimi (602-545-01).

2.2. Experimental protocol

Before and after the training program, all patients performed pre- and post-test measurements of shoulder flexion strength with a voluntary maximal isometric contraction with shoulder positioned at 5° of flexion (0° corresponding to reference anatomical position) and with the elbow in full extension. Strength measurements were carried out with the robotic-assisted device AME (American Certificate US.8.262.541, US.8.187.152; Canadian certificate CA 2714914) for the RA-EMG group and with a dynamometer for the Conv group. Active shoulder flexion range of motion was collected using a manual goniometer. Thereafter, the patients completed a training program, with conventional approach or with robotic-assisted combined with EMG biofeedback, during 8 consecutive weeks with 3 sessions a week. Each training session started with a 10-minute warm-up period of aerobic exercise (treadmill, cycle ergometer or stair climber machine) in low to moderate intensity (rated 1 to 4 on the modified Borg scale) [31]. To complete the warm-up, a 5-minute exercise consisting in voluntary shoulder movement adjusted to individual functional

limitations in the frontal, sagittal and transversal plans was performed without any external intervention. After which, each group performed specific training with AME or conventional approach.

2.3. Training programs

2.3.1. RA-EMG group

The RA-EMG group carried out an 8-week strength training program using AME device with 2 sets of 20 repetitions, 3 sessions a week. A rest period of 1 min 30 sec was observed between series [32].

The patient was seated and the axis of shoulder rotation aligned with the axis of rotation of the AME device. The position parameters were stored in the device interface that reproduced settings between sessions [33]. Surface EMG electrodes (Thought Technology Ltd., Canada) were placed on the anterior deltoid [34,35]. A two-channel Myotrac Infinity Encoder (Thought Technology Ltd., Canada) monitored the EMG activity during training sessions. Data acquisition was performed at a frequency of 2048 Hz and collected by the internal computer of the AME device.

Maximal isometric shoulder flexion was performed before starting each training session to determine the maximal EMG activity. The exercises consisted in performing shoulder flexion and extension from 0-30° to a maximum of 90°. Movements were performed at a level of 60% of the maximal EMG activity displayed on a screen in front of the patient. The speed control system of the AME device adjusted the load based on the EMG activity.

2.3.1. Conv group

The CONV group performed an 8-week strength training program using dumbbell weight consisting in 2 sets of 20 repetitions with a rest period of 1 min 30 sec between sets, 3 sessions a week. Dumbbell weight loads were adjusted based on patient capacity throughout the program based on 60% of the maximal capacity. The two shoulders were randomly trained. The exercises were elbow flexion, shoulder anteflexion, shoulder abduction and shoulder elevation.

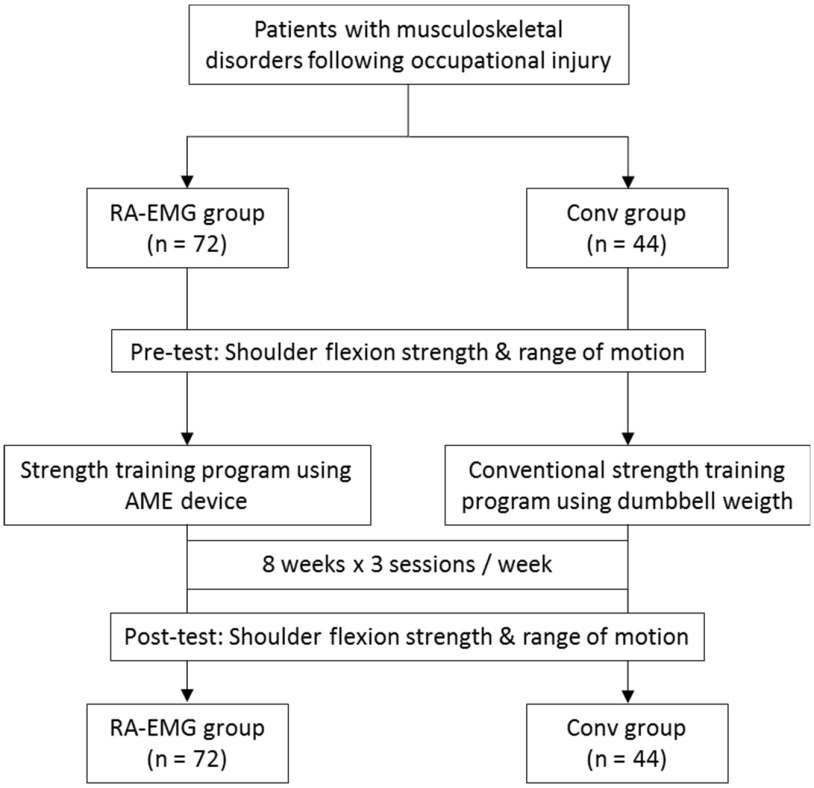

Figure 1. Study design & flow chart. RA-EMG group: Robotic-assisted with electromyography feedback; Conv group: conventional training.

2.4. Outcomes

2.4.1. Absolute and normalized shoulder flexion strength gain

Absolute shoulder flexion strength gain was assessed with a voluntary maximal isometric contraction of shoulder flexion. Absolute strength gain was calculated between the pre- and post-session (Absolute Strength gain (kg) = Post strength – Pre-test strength).

The normalized shoulder flexion strength gain is expressed as a percentage from the pre-test session. (Normalized strength gain (%) = (Absolute strength gain / Pre-test strength * 100)). This variable compensates for an amplitude of strength produced by each person and refers to a percentage increase of strength produced at the end of the program.

2.4.2. Absolute and normalized shoulder flexion range of motion gain (ROM)

The absolute shoulder flexion ROM gain of each patient was calculated with help of a manual goniometer. The amplitude gain was estimated between the first and the last session of the program: ROM gain = Post-test ROM – Pre-test ROM.

To calculate the normalized shoulder flexion ROM gain, we divided the absolute amplitude by the maximum absolute amplitude at the pretest and multiplied by 100 (Normalize ROM gain = (Absolute ROM gain / Pre-test ROM * 100)).

Statistical analysis

The statistical analysis assessed the effects of two 8-week strength rehabilitation programs (Conv versus RA-EMG) on strength gain and ROM in patients presenting with shoulder MSDs (SigmaPlot, version 12.5, Systat Software inc., USA). The Shapiro-Wilk test tested normality of the data. Mann-Whitney test was performed for strength gain, and T test for independent measure was performed for ROM gain and demographic characteristics. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Population charateristics

Considering the nature of this retrospective cohort study, seventy-two participants (51 males and 21 females) aged 27-72 years (48.0 ± 8.9 years) were allocated to the RA-EMG group, while 44 participants (28 males and 16 females) aged 32-61 years (45.3 ± 7.2 years) were in the COV group (Table 1). The RA-EMG group performed 19.0 ± 4.3 training sessions in 51.0 ± 13.9 days, and the CONV group performed 20.6 ± 4.7 conventional training sessions in 55.8 ± 25.5 days. At baseline, subacromial pain syndrome was diagnosed in 81.8% and 81.9% of the CONV and RA-EMG groups, respectively. No significant difference ($p > 0.05$) was observed comparing age, training duration and number of sessions between groups (Table 1).

Table 1 : Baseline characteristics for the RA-EMG and CONV group

	RA-EMG group N=72	**CONV group N=44**	**p value [t value]**
Sex, n (%)			
Men	51 (70.8)	28 (63.6)	0.940
Women	21 (29.2)	16 (36.4)	0.169
Age (years ± SD)	48 ± 8.9	45.3 ± 7.2	0.092 [1.700]
Training duration (days ± SD)	51.0 ± 13.9	55.8 ±25.5	0.188 [1.324]
Number of sessions (days ± SD)	19.0 ± 4.3	20.6 ± 4.7	0.064 [1.872]
Classification of diseases, n (%)			
Subacromial pain syndrome	59 (81.9)	36 (81.8)	-
Shoulder dislocation	4 (5.6)	5 (11.3)	-
Other shoulder MSDs	9 (12.5)	3 (6.8)	-
Flexion shoulder strength (kg ± SD)	6.2 ± 3.5	7.6 ± 3.9	
Range of motion (degrees ± SD)	141.8 ± 31.2	138.3 ± 34.6	

MSDs: musculoskeletal disorders; SD: Standard Deviation.

3.1. Absolute and normalized shoulder flexion strength gain

The RA-EMG group showed significantly greater absolute strength gain than the CONV group after the training program (4.9 ± 2.6 kg vs 3.8 ± 4.98 kg, respectively, U = 321.5, p = 0.014) (Figure 2, upper panel). In addition, significantly greater benefit for normalized strength was observed in the RA-EMG group (103.1 ± 86.9 %) in comparison with the CONV group (67.0 ± 92.1 %, U Statistic = 325.0, p = 0.016) (Figure 2, lower panel).

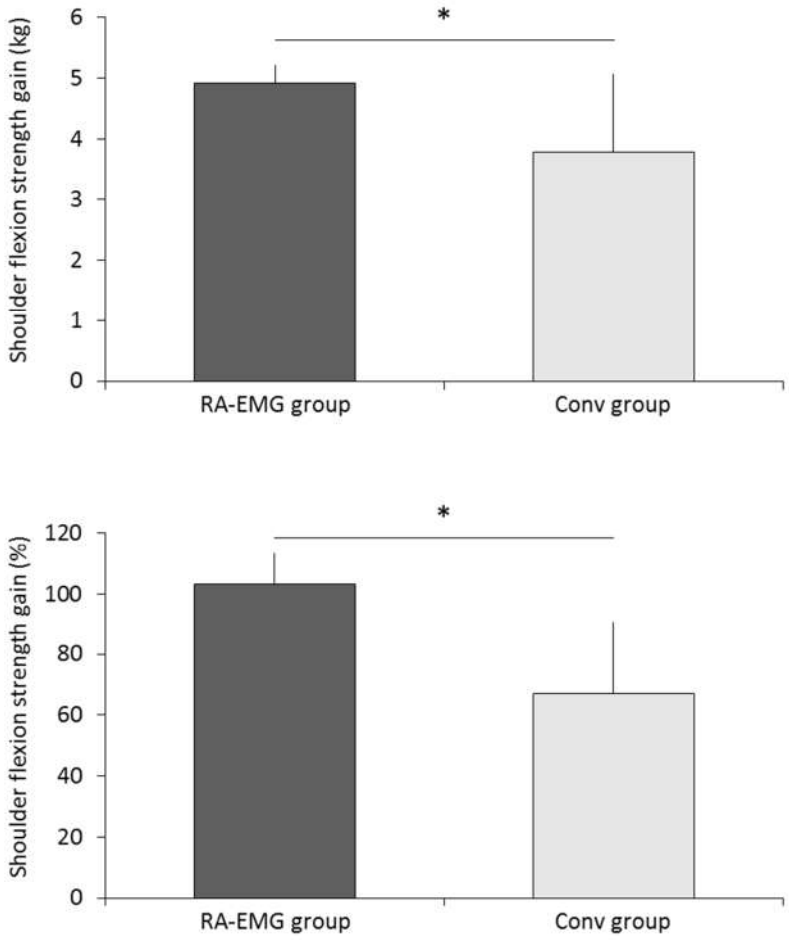

Figure 2. Mean and standard error of absolute (upper panel) and percentage (lower panel) of shoulder flexion strength gain. * $p < 0.05$, indicating greater strength gain in RA-EMG than CONV group.

3.1. Absolute and normalized shoulder flexion ROM gain

After the training program, the RA-EMG group showed significantly greater absolute gain of ROM than the CONV group (15.66 ± 2.57 vs 6.39 ± 1.95 degrees, respectively, p = 0.012) (Figure 3, upper panel). In addition, significantly greater benefit in normalized ROM was observed for the RA-EMG (14.4 ± 3.0 %) than the CONV group (6.1% ± 1.9, p = 0.046) (Figure 3, lower panel).

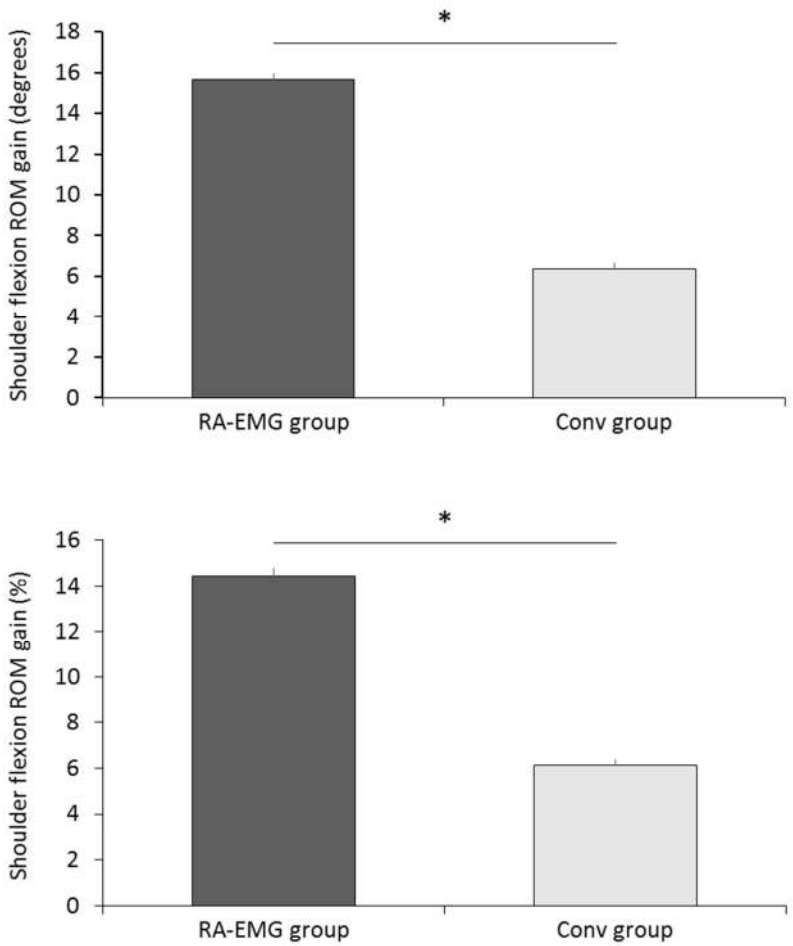

Figure 3. Mean and standard error of absolute (upper panel) and percentage (lower panel) of shoulder flexion range of motion (ROM). * $p < 0.05$, indicating greater strength gain in RA-EMG than CONV group.

4. Discussion

This study showed that a robotic-assisted training program combined with EMG biofeedback led to greater gain of shoulder flexion strength and range of motion compared to a conventional strength program. This study provides new insight, showing the added value of a robotic-assisted program combined with EMG biofeedback device in MSDs population.

By using a similar device in an 8-week strength program (3 sessions/week) in healthy adults, Bui et al. [30] reported up to 26% of strength gain in both right and left shoulder flexion. While relative gain was reported in healthy adults, our study showed that robotic-assisted device combined with EMG biofeedback in an MSD population provided up to 103% of strength gain in comparison with the 67% observed with conventional rehabilitation. In a recent systematic review, Argut et al. [29] indicated that EMG biofeedback can be effectively help to improve quadriceps strength. Gumaa and Rehan Youssef [36] showed in their literature review that evidence of the effectiveness of virtual reality or augmented environment is promising in the shoulder impingement syndrome, supporting

the idea that more playful and personalized rehabilitation is beneficial for the patient.

Associated with strength, ROM has been identified as a critical component in MSD shoulder rehabilitation [19,37]. In a systematic review and meta-analysis, Steuri et al. [19] determined the effectiveness of conservative interventions for range of motion in 6093 adults with shoulder impingement through 113 trials. This study reported that specific exercise therapy was superior to non-specific exercise, and that manual therapy plus exercise was superior to exercise only. In line with these findings, our results showed that specific guided exercise rehabilitation program provided higher ROM outcomes in comparison with conventional therapy. The AME device presented an added value for the management of ROM in patient with MSD syndrome and might be enhanced by combining it with manual therapy.

In addition to potentiating strength and ROM rehabilitation, EMG biofeedback was used to ensure adequate activation of muscle involved in a given exercise [37–43]. The AME device adjusted the level of resistance force, until total passive movement [46], to provide constant EMG activity [45], allowing to take into account fatigue components during a training session. Whereby, maximal EMG activity was determined before each training session considering the current strength capacity and achievement over the training period program in compliance with the recommendations of active and progressive rehabilitation for shoulder MSDs [13,47,48]. Previous studies argued that EMG biofeedback increases patient motivation [44, 45] and facilitates patient compliance by modulating muscular activity in a real-time manner [46,47,48]. In line with this finding, AME device and EMG activity feedback (i.e. a standardized measurement protocol) participated to individualization, person-centered care and participative rehabilitation approach [53].

Even though our study presented clear evidence favoring RA-EMG in management of shoulder MSDs, some concerns should be considered. First, only strength and ROM were clinically assessed, while it has been recommended to evaluate pain and functional disability [19]. Similarly, abduction and external rotation should be treated to restore and involve agonist and antagonist muscles. Since the final goal is to return to work [55], the period of rehabilitation before returning to work could also be considered as a key endpoint. Finally, future randomized controlled trials should be conducted to improve the level of evidence.

5. Conclusions

The current retrospective cohort study showed that a robotic-assisted device combined with EMG biofeedback provided greater strength and range of motion shoulder flexion after an 8-week rehabilitation period in comparison with a conventional approach in patients with shoulder MSDs. EMG activity as biofeedback offered a tailored rehabilitation program with constant effort by adjusting automatically the level of resistance based on a specific EMG target, and may have t enhanced patient motivation. Future research with a randomized controlled design should determine the potential added value of a robotic-assisted device combined with EMG biofeedback on abduction and external rotation

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Informed Consent Statement: Informed consent was waived because of the retrospective nature of the study and the analysis used anonymous clinical data. An information letter and a non-opposition form was sent to all patients.

Data Availability Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

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