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Neuromuscular Electrical Stimulation Superimposed on Movement and Isoinertial Training for Rotator Cuff-Related Shoulder Pain: A Case Report and Literature Review

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Abstract

Objectives: Assessing the effectiveness of a novel exercise protocol, with Neuromuscular Electrical Stimulation superimposed on movement (NMES+) and isoinertial training for the treatment of Rotator Cuff-Related Shoulder Pain (RCRSP) in a master swimmer.

Design: Case report.

Participant: The patient was a 44-year-old master swimmer who began complaining of shoulder pain after the Italian Championships tournament. Following an orthopedic examination the subject was diagnosed with supraspinatus tendinopathy and commenced a period of rest, corticosteroids and electrotherapy which led to no benefit to his shoulder symptoms. Subsequently, a structured exercise rehabilitation program including NMES superimposed on movement and isoinertial training was started with the aim of returning to sport avoiding a surgical intervention.

Rehabilitation exercise proposal: A step-by-step rehabilitation exercise protocol was proposed focusing on load and exercise progression with the goal of strength, power and mobility recovery. NMES+ was used to support early rehabilitation, while isoinertial training was used in the mid-late stage of the rehabilitation process.

Conclusion: The protocol allowed the subject to successfully return to autonomous gym training and swimming in 10 and 11 weeks respectively, following the rehabilitation exercise program. The novel NMES and isoinertial training approaches may be considered as promising tools in RCRSP rehabilitation.

Keywords: NMES; Isoinertial; Flywheel; Shoulder; Case report

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Introduction

RCRSP is defined as a multi-factorial condition that covers different shoulder morbidities including sub-acromial-related pain and rotator cuff tendinopathies. It approximately affects 30% of the human population and is considered as the main cause for the development of pain symptoms in the shoulder joint [1]. In sports requiring frequently combined shoulder activation and wide range of motion (e.g. swimming, volleyball, tennis etc.) RCRSP is peculiar due to the repetitive shoulder activity and tissue loading while executing sport-specific tasks [2-4]. In the general population, RCRSP is often associated with a natural decline of the muscle-tendon unit tissue quality which increased with aging, with a peaking incidence after 50 years of age [5-7]. In addition, intrinsic environmental factors such as obesity, diabetes, waist circumference, age, genetic features, hypertension and dyslipidemia may play an influencing role in the incidence rate and severity of symptoms [8-14].

In patients with RCRSP, Quality of Life (QoL) is affected by a significant decrease of strength, function, and motion [15]. The presence of pain when performing overhead tasks has been shown to be typical [4] and accompanied by neuromuscular and coordinative alterations among rotator-cuff muscles. Furthermore, altered scapular kinematics is often associated to RCRSP [16-19].

To date, conservative treatment is considered as the first-line treatment option for the management of such pathology and, therefore, surgical intervention is advocated after the rehabilitative approach failure or in case of traumatic tendon tears only [20].

When standard rehabilitation protocols are implemented, it might be difficult achieving selective muscle strengthening of the involved shoulder muscles in the early stages, since high-intensity and/or fast movements may not be compatible with the reduced mobility; the limited tissues load capacity, and the increased pain perception characterizing these phases.

Recent studies supported the use of Neuromuscular Electrical Stimulation superimposed on movement (NMES+) as a promising option in RCRSP since it produces externally induced muscle contractions that, in association with voluntary exercise, may help increasing active motion, voluntary activation and strength [21-25]. This method provides selective muscle activation and fosters full shoulder range of motion restoration with temporary but immediate remission of clinical symptoms [21].

However, evidences regarding the use of NMES+ for RCRSP are lacking.

The existing therapeutic exercise concept for the treatment of shoulder tendinopathy comprises mechanical load of the injured tissue throughout the execution of different tasks focusing on Eccentric Exercises (EE), which stimulate the development of collagen fibers' cross-linking thus promoting tendon repair [26,27]. Accordingly, EE is recognized as a basic element in exercise therapy for rehabilitation of tendinopathies [28-32].

Nevertheless, emerging evidences indicate that the execution of both concentric and eccentric phases of the stretch-shortening cycle, and not only EE5 [33-36], is beneficial to achieve a complete and efficient load adaptation of the tendon [37-39]. In light of the above, isoinertial training may embody an effective tool to carry out a stimulus composed of repetitive concentric and eccentric muscle contractions. When implementing isoinertial training the force applied to the flywheel by the person during the concentric phase of movement determines the load in the eccentric phase [40]. During the concentric phase, the energy is stored and subsequently released along the eccentric phase as resistance, leading to a greater activation of the muscles in this phase compared to standard isotonic training systems [41]. The isoinertial training paradigm has also been used as an aid in the treatment and prevention of lower limbs' tendon injuries and may play a relevant role in musculoskeletal rehabilitation [42-44]. Unfortunately, no studies have investigated isoinertial training as a tool in musculoskeletal rehabilitation for the upper limb yet.

Therefore, the aim of this case report is to show the effectiveness of a novel rehabilitation program, which includes NMES superimposed on movement and isoinertial training as part of the exercise progression for the conservative treatment of RCRSP in a master swimmer.

Methods and Results

This case report was structured following the CARE Checklist. The filled checklist is provided in the "Appendix" section.

Case description

The patient was a 44-year-old man competitive master swimmer, mainly backstroker (body mass 70 kg, height 1.83 m and body mass index 20), with no history of previous surgery or injury to the upper body. Left shoulder pain symptoms appeared in the first place in January 2019. After 4 months of pain management with no need for rehabilitation and/or sport practice modification, pain in his shoulder increased forcing him to stop his sport practice following the Italian Championships held in June 2019.

An MRI scan showed acromioclavicular chondropathy, reactive phenomena with associated joint capsule redundancy and concomitant reduction of the sub-acromial space. The supraspinatus tendon appeared non-homogeneous at its pre-insertion and insertion portions with moderate inflammatory phenomena in the pericoracoid site. Minimal involution phenomena in the glenoid labrum and in the anterior inferior site of the glenoid cavity were detected. Reactive tenosynovitis phenomena were observed along the path of the long biceps brachii tendon.

Following the MRI scan the patient was scheduled for an orthopedic examination. The subject completed the first Disabilities of the Arm, Shoulder and Hand (DASH) [45] questionnaire and was then diagnosed with RCRSP syndrome, prescribed methylprednisolone and concomitant elastic bands strengthening of the scapular stabilizer muscles with the advice of avoiding overhead shoulder motion for two weeks. In addition, the patient was scheduled for a left shoulder X-ray which detected calcifications of the periarticular soft tissues possibly from supraspinatus enthesopathy.

Initial rehabilitation period

After the failure of the first treatment approach, the patient opted for a second orthopedic examination in July 2019. Strengthening was then interrupted and the patient was prescribed radial shockwaves and corticosteroid injections, and scheduled for a comparative left shoulder X-ray at the end of the period.

After the injections (one every three weeks) and shock waves (one per week) over a period of six weeks in total (15th of July to 31st of August 2019) no beneficial effects were noted. In the following orthopedic follow-up consultation, the comparative X-ray showed a reduction in calcium apposition while the clinical examination highlighted an increased pain perception as well as a decreased function in terms of active and passive shoulder elevation.

The subject was then prescribed corticosteroids injections with the same frequency (one every three weeks) combined with pulsed Neodymium: Yttrium-Aluminum-Garnet (Nd:YAG) laser and diathermy therapies for a period of four weeks (17th of September to 18th of October 2019), that ended again with no success. After the failure of the prescribed multiple passive treatments, an exercise therapy progression was proposed before considering a surgical intervention. The overall initial rehabilitation period is summarized in Table 1.

Rehabilitation exercise protocol

After one month of rest, in January 2020, the patient started a rehabilitation period with two supervised rehabilitation sessions per week with a combined daily home-based exercise program which was updated every two weeks, for a total duration of twelve weeks. The exercise progression was chosen according to the patient's

Table 1: Summary of clinical progression from injury to rehabilitation exercise program.

	Exam	Results	Prescription
6/13/2019	MRI left shoulder	Non-homogeneity of supraspinatus tendon	
		Minimal reactive phenomena in the subacromial region and in the subacromial bursa	
		Modest inflammatory phenomena in the pericoracoid site	
		Tenosynovitis of biceps brachii tendon	
6/25/2019	Orthopedic examination	Left shoulder pain for 6 months with no traumatic event	Ice bag for 2 days and stop swimming
		Clinical evaluation: complete passive ROM, painful and limited active shoulder flexion improving in lying position.	Methylprednisolone 16 mg 1 cp die for 5 days to scale ½ cp die for 5 days and after ¼ cp die for 5 days
		Positive tests: JOBE, NEER, SIGN, PALM UP	Elastics bands strengthening of scapula stabilizers for 20 days
		Negative tests: NAPOLEON, LIFT OFF, PATTE	Left shoulder X-ray to investigate calcific tendinopathy
		Diagnosis: Subacromial impingement with scapular dyskinesis	
6/27/2019	DASH questionnaire	Score 47.36%.	
6/28/2019	X-ray Left shoulder	Preserved glenohumeral joint space in the presence of thin scapular glenoid sclerosis	
		Periarticular soft tissue calcifications possibly from supraspinous enthesopathy. Preserved morphology of the humeral head	
		Reduction of subacromial space	
7/12/2019	Orthopedic examination	No beneficial effects after the first rehabilitation approach	Comparative X-ray
			Radial shock-waves
			Corticosteroids injections
			Stop strengthening
9/3/2019	X-ray Left shoulder	Reduction of calcification in the left humeral tuberosity	
9/17/2019	Orthopedic examination	Symptoms not improved	Nd: YAG laser, diathermy and corticosteroid injections
		Night pain	
		Significant pain perception in active and passive elevation	
		Positive clinical tests: PATTE; PALM UP	
		Negative clinical tests: NAPOLEON	
		Not assessable test: JOBE	
		Corticosteroid subacromial injection with anesthetic	
10/18/2019	Orthopedic examination	Symptoms not improved	Possible surgical procedure of cuff suture, calcification removal and acromioplasty
		Significant pain perception in active and passive elevation	
		Night pain	
		Positive tests: NEER SIGN, JOBE, WIPPLE	
		Negative tests: PALM UP, YOCUM, NAPOLEON, LIFT OFF, PATTE	
		Pressure pain at supraspinatus level	

MRI: Magnetic Resonance Imaging; DASH: Disability of the Arm, Shoulder and Hand; Nd-YAG: Neodymium:Yttrium-Aluminum-Garnet

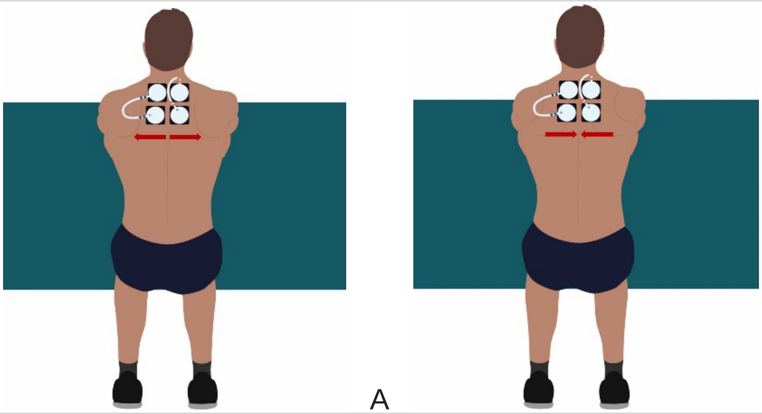
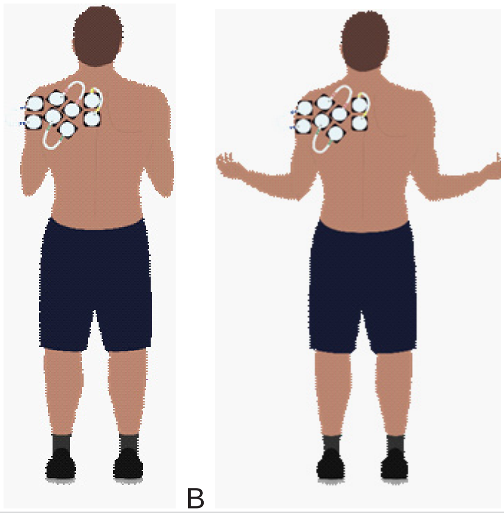
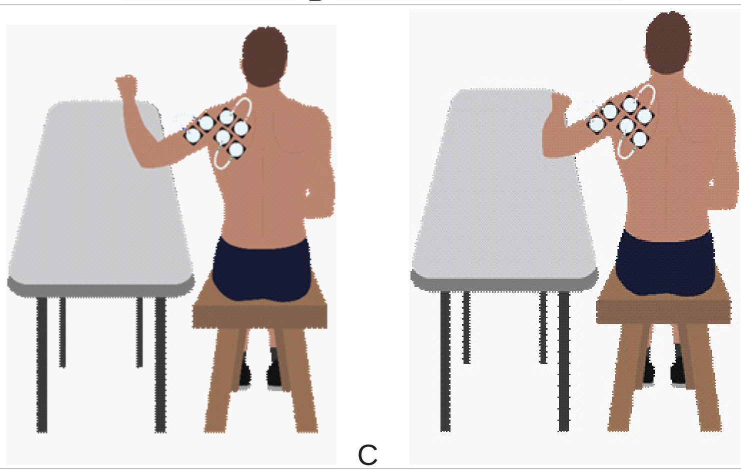
preferences and with a physiatrist's supervision using active exercises only and allowing the execution of exercises with a pain perception up to five out of ten on a Numeric Pain Rating Scale (NPRS). The first two weeks were focused on gaining mobility and the exercise selection included external/internal rotation and scapular abduction/adduction exercises combined with NMES+. The NMES+ approach was selected for the early stages of rehabilitation. A 4-channel wireless portable battery-powered stimulator (Chattanooga Wireless Professional), which produces a rectangular, balanced monophasic pulse, was applied with self-adhesive electrodes (Compex Dura-Stick plus 5 cm × 5 cm). Electrodes were positioned following the anatomical site of scapular retractors (mid-lower trapezius and rhomboids) and external rotators (infra/supraspinatus, teres minor, and posterior deltoid), as indicated in Table 2. For each NMES+ application, two different current frequencies were alternatively used (35 and 50 Hz on different days) to stimulate both slow- and fast-twitch muscle fibers targeting a comfortable muscular stimulation [46,47].

In each active task combined with NMES+, the active stimulation lasted 8s followed by 8s of rest, thus creating a duty cycle of 16s. The duration of the concentric and the eccentric contractions were 3s and 5s respectively.

In the first two weeks, the patient performed scapular adduction/abduction motion with NMES+ in kneeling position (first week) (Table 2A) and external/internal rotation motion in standing position (Table 2B). The electrical current intensity was progressively increased session by session according to subjective tolerance.

The third and fourth weeks were focused on restoring frontal plane mobility while consolidating internal/external rotational strength. To reach this goal, isoinertial training was introduced. Despite the physiological adaptations of isoinertial training in lower limbs are known, evidence of the effects of this training method in upper limbs are lacking. In light of this, we decided to apply such training approach in controlled external/internal rotation movements which were broadly practiced in the previous weeks and on which the subject felt confident (Table 3A, 3B).

Table 2: NMES exercises. NMES: Neuromuscular Electrical Stimulation.

Exercise	NMES application
Scapular adduction/abduction standing on all fours	 A
Standing shoulder external/internal rotation (0° abduction)	 B
Seated shoulder external/internal rotation (70° to 90° abduction)	 C

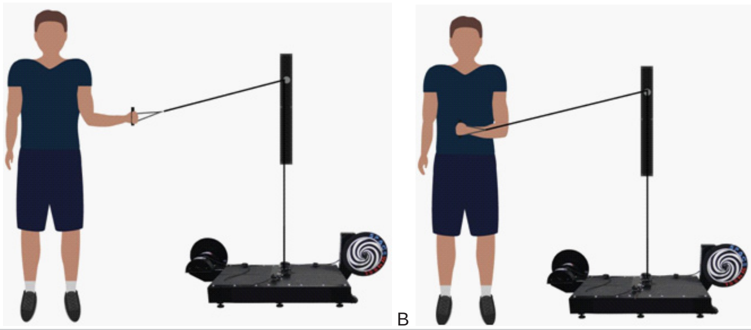
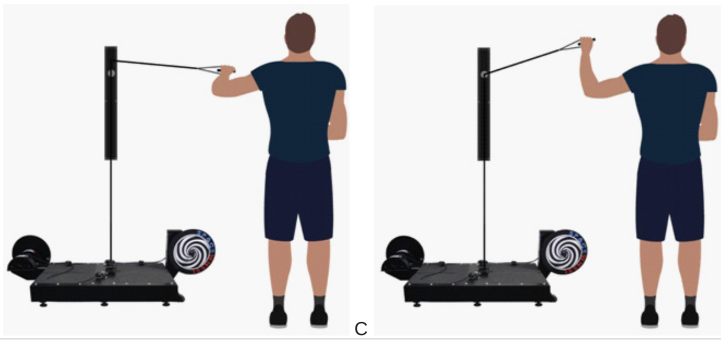
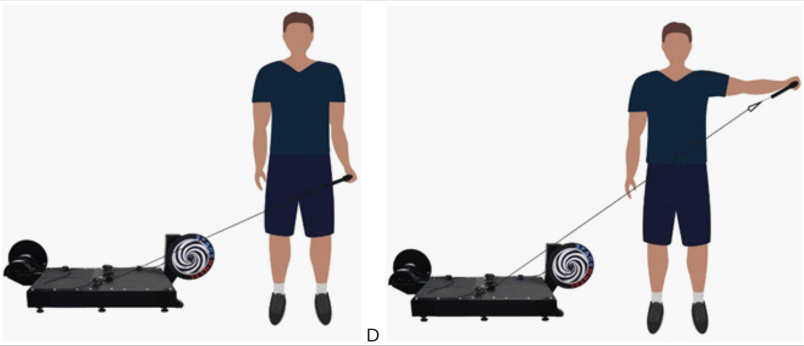
We used a versatile isoinertial device (Space wheel, Rivarolo Canavese, Turin, Italy) providing both upper and lower limb training options, equipped with two different fly wheels. The two fly wheels differ in the pulley technology. One is dedicated to rehabilitation and allows for a gentle concentric-to-eccentric transition since the unique pulley technology rolls the rope in concentric circles. The other is the traditional cylindric flywheel technology dedicated to performance with a stronger concentric-to-eccentric transition, thus allowing for an increased muscle activity in breaking the eccentric phase of movement. Detailed isoinertial training proposal is illustrated in Table 3.

In this period, the subject started to perform unloaded active abduction/adduction exercises as well as external/internal rotation movements with NMES+ with the arm supported at 70° to 90° abduction (Table 2C).

Fifth and sixth weeks targeted the approach of overhead frontal plane movements, continuing with NMES+ and isoinertial training, adding high intensity resisted rowing exercises. At this point in time, according to symptoms' improvements, facilitated pushups and biceps curl were introduced in the exercise protocol.

Seventh and eighth week focused on consolidating strength during abducted external rotation, moreover abducted isoinertial rotational training (70° to 90° of arm abduction) with no support

Table 3: Isoinertial exercises.

Exercise	Isonertial application
Standing external rotation (0° abduction)	 A
Standing internal rotation (0° abduction)	 B
Standing external rotation (70° to 90° abduction)	 C
Lateral raises	 D

(Table 3C) was included in the program. Complete pushups were included into the program and NMES+ was discontinued.

Return to sport

After a clinical examination with a physiatrist who attested close to full ROM recovery, the patient was allowed to progressively come back to autonomous gym training and scheduled for a functional assessment test battery. During the last rehabilitation phase weekly supervised attendance was lowered to one session per week and one autonomous gym session per week was added.

Ninth and tenth weeks hinged on building up upper body muscle mass opting for a multi-joint movement program (shoulder press, bench press, pull-ups, etc.) carried out in the autonomous gym schedule, while increasing the power output and approaching plyometrics exercises in the supervised sessions.

Eleventh and twelfth weeks focused on heavy loading at the gym while restoring load capacity in the last degrees of the shoulder ROM and re-training overhead throwing and isoinertial abduction (Table 3D). The full training program is listed in Table 4.

After completing the functional test battery, filling the second DASH questionnaire and undergoing a second MRI scan in October 2020, the patient was allowed to perform unrestricted sport activities. Conducting an MRI examination at this stage had the study purpose

Table 4: Rehabilitation program with exercise progression. NMES+: Neuromuscular Electrical Stimulation superimposed on movement.

Weeks	Exercises	References
1-2 weeks	Pendular exercise	[15,48-60]
	External rotation with elastic bands (0° abduction)	
	NMES+ on scapular adduction/abduction and external/internal rotation (0° abduction)movements	
	Sleeper Stretch	
3-4 weeks	Unloaded adduction /abduction mobility	[15,50,51,55,57,61]
	Unloaded external rotation in abduction (70-90°)	
	Frontal plane mobility exercises	
	NMES+ on external/internal rotation with supported abduction (70-90°)	
	Isoinertial external rotation work (0° abduction)	
5-6 weeks	Resisted rowing exercises	[15,49,51,62]
	Frontal plane overhead movements	
	External rotation with elastic bands (70-90° of abduction)	
	NMES+ on external/internal rotation with supported abduction (70-90°)	
	Isoinertial external/internal rotation training (0° abduction)	
	Inclinepush ups	
	Biceps Curl	
7-8 weeks	Single handed kneeling weight bearing	[63–66]
	Overhead wall slide with fitball	
	Push ups	
	Isoinertial external/internal rotation training (0° abduction)	
	Isoinertial external/internal rotation training in abduction (70-90° of abduction)	
9-10 weeks	Autonomous gym schedule (1x week)	[63,67–72]
	Elastic bands military press	
	Elastic bands lateral raises	
	Plyometric drop and catch	
	Single handed weight bearing	
	Facilitated plyometric push ups	
	Isoinertial external/internal rotation training in abduction (70°-90° of abduction)	
11-12 weeks	Autonomous gym schedule (1x week)	[66,73,74]
	Isoinertial lateral raises	
	Plyometric push ups	
	Doorway fall	
	Resisted overhead throwing backward and forward	
	Back to the pool	

to compare functional improvement with imaging findings only. For the overall timeline of the rehabilitation period (Figure 1).

Functional assessment

Functional assessment was not performed at the beginning of the treatment because of pain-driven limitations. Therefore, the decision was to implement such evaluation at the end of the treatment with the target to obtain return to sport criteria. The testing procedure included the evaluation of shoulder ROM, and maximum voluntary isometric contraction of shoulder internal/external rotator muscles using the Dynatorq device (Easytech, Florence, Italy).

The Dynatorq device is designed for functional assessment and rehabilitation of the shoulder and is equipped with an extensometer placed in the center of the rotor [48,49]. The device allows to fully analyze shoulder strength and motion and in particular internal-external rotation with selected abduction (Figure 2A, 2B), adduction/abduction (Figure 2C), and flexion/extension (Figure 2D).

Maximum voluntary isometric tests were performed for internal/external rotator muscles with both 30° and 90° of arm abduction. Detailed Dynatorq results are listed in Table 5.

DASH score

The DASH questionnaire was used to evaluate the patient's ability to perform the activities of daily living before and after the rehabilitation program. The DASH questionnaire is widely adopted for assessing an individual's ability to perform tasks, absorbing forces and the severity of symptoms [50]. The first DASH was recorded the day before the rehabilitation program started on June 27th, 2019, scoring 47.36%. The second DASH was recorded when the subject was about to return to sport (swimming) on June 22nd, 2020 marking

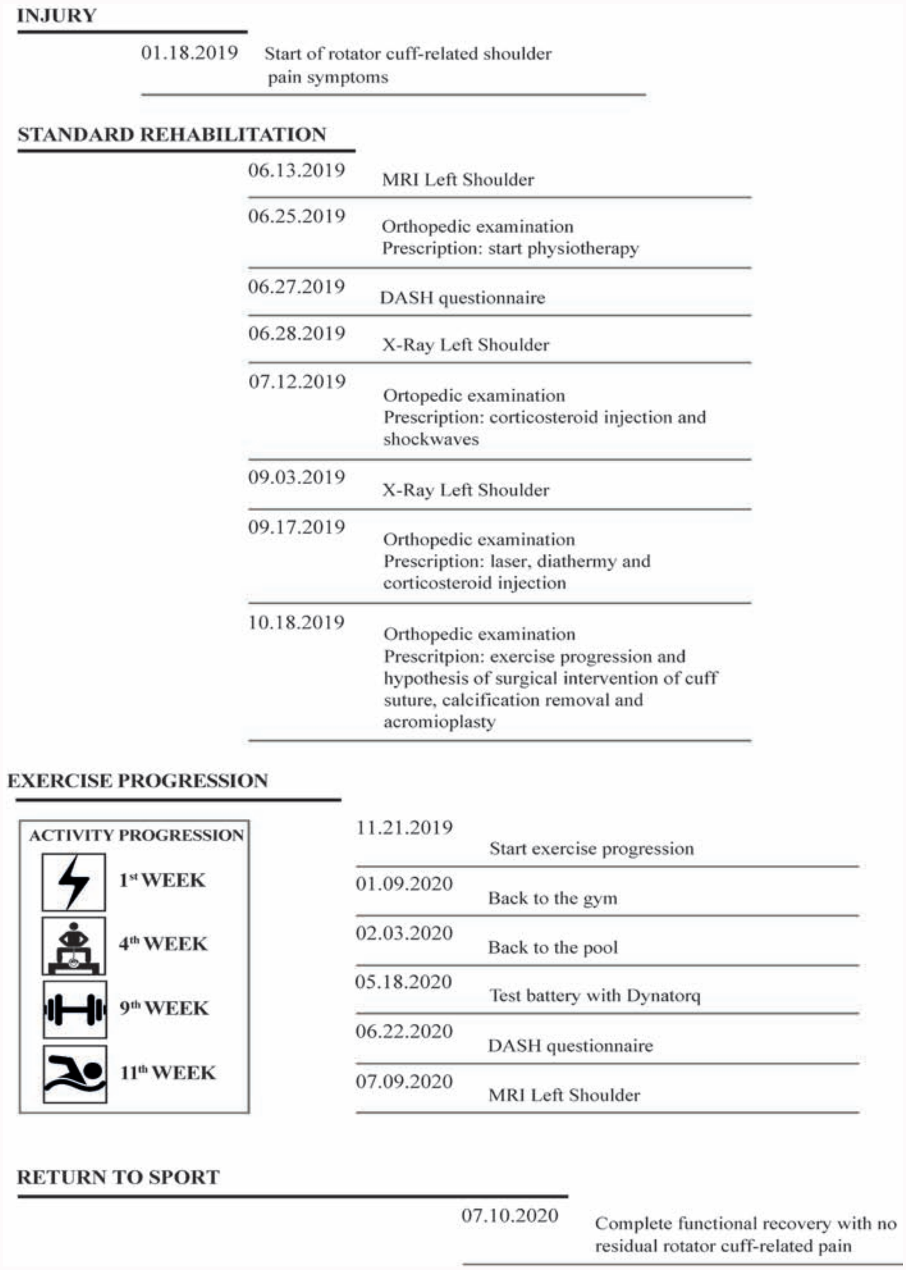


Figure 1: The overall timeline from injury to return to sport. The icons in the table represent the NMES+ started in the first week, the isoinertial training started in the fourth week, the return to the gym in the ninth week and the return in the pool in the eleventh week, respectively.

a score of 14.28%.

Discussion

To the best of our knowledge, this is the first study describing in details an exercise rehabilitation program for rotator cuff-related pain including NMES+ and isoinertial training. The results of the implemented approach further confirm that rehabilitative active exercise progression should be the first-line approach when considering RCRSP with no presence of red flags (trauma, mass or swelling, red skin, fever etc.) [20,51-53]. RCRSP is a common condition in overhead sports (baseball, volleyball, swimming, etc.) and in elite swimmers, with supraspinatus tendinopathy being recognized as one of the most relevant causes of shoulder pain [54-56]. In this study, a 44-year-old competitive master swimmer began experiencing shoulder pain during the competitive season and was forced to stop as the perceived pain became unmanageable.

The study subject underwent an MRI scan (Figure 3A, 3B) and an orthopedic examination, resulting in a RCRSP diagnosis.

Initially, the patient was treated with oral corticosteroids, ice, and scapular stabilizer muscles strengthening for three weeks, with no beneficial effects. Subsequently, the subject was prescribed radial shock waves and corticosteroid injections while discontinuing muscle strengthening, without remarkable benefits; lastly, the patient was treated with injections combined with radial shockwaves, Nd:YAG laser and diathermy therapies. This period, characterized by a transition to passive treatments only, lasted from June to October 2019 and brought no improvements in terms of shoulder symptoms. Early passive approaches are not supported by the scientific literature, in particular: 1) corticosteroids injections are shown to have a

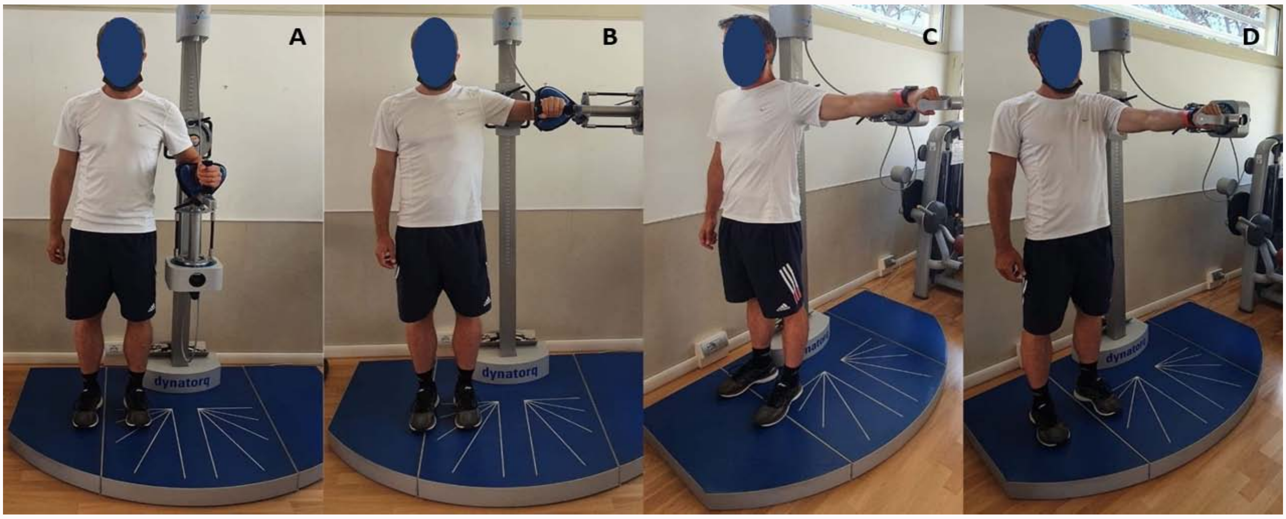


Figure 2: Functional assessment on Dynatorq device. A-B: Starting positions of maximum voluntary isometric contraction tests; C-D: Captures during active range of motion tests.

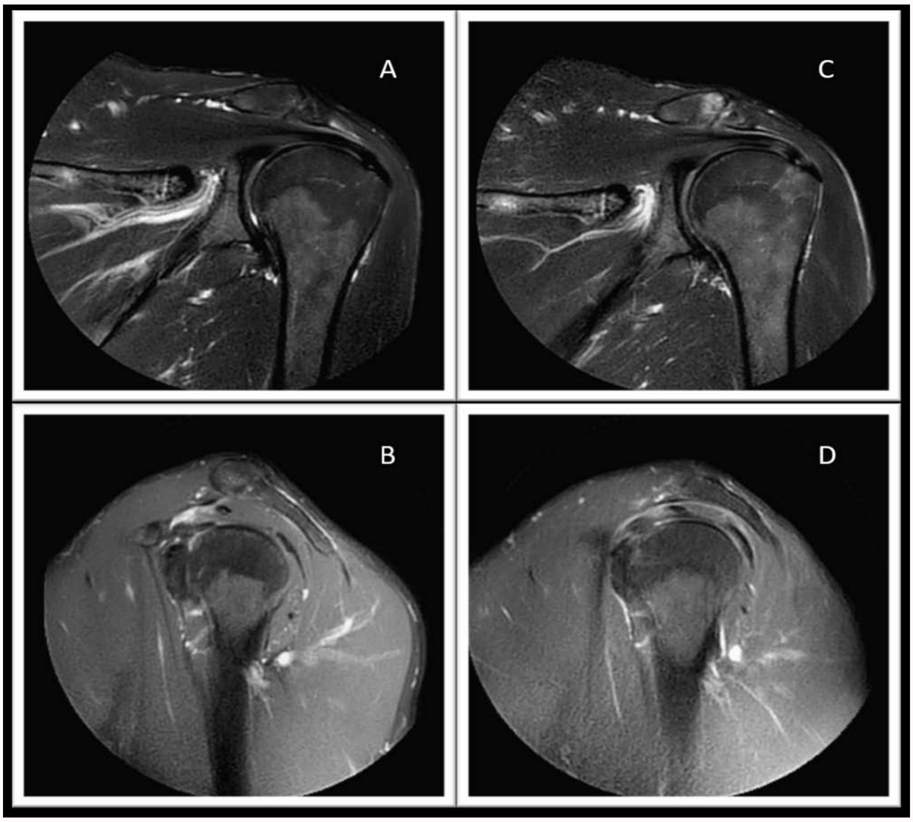


Figure 3: (A-C) T2 SPAIR weighted coronal view, (B-D) PD SPAIR weighted sagittal view. Pre-treatment (A-B), and post-treatment (C-D) shoulder MRI showing no substantial changes.
SPAIR: SPectral Attenuated Inversion Recovery; PD: Proton Density

moderate pain-relief effect only in the short-term (3 to 8 weeks) for RCRSP symptoms [57,58] as well as possible adverse effects [59] and to be related to an increased revision rate after a primary rotator cuff repair surgery [60-63], 2) radial shock waves are shown to provide no clinically relevant benefits in RCRSP management compared to placebo [64]; 3) combining Nd:YAG laser therapy with exercise seems to have little or no improvements in shoulder pain and function compared to exercise alone [65,66], 4) high-frequency diathermy, when added to exercise, is shown to provide little or no benefits in pain and function [20,67,68]. All of these passive approaches should be considered as an adjuvant of exercise progression only which remains the first-line evidence-based treatment approach when considering RCRSP [20].

After this initial conservative approach, the subject of this case report was prescribed a rehabilitative exercise therapy progression

Table 5: Results of range of motion and maximum voluntary isometric contraction tests.

ISOMETRIC STRENGTH			
Shoulder position	**Right (Healthy dominant)**	**Left (Injured non-dominant)**	**Side-to-side (%)**
Internal rotation, 30° abduction (Nm)	45	47	4
External rotation, 30° abduction (Nm)	35	32	-9
Internal rotation, 90° abduction (Nm)	36	37	3
External rotation, 90° abduction (Nm)	36	39	8
External/Internal ratio, 30° abduction (%)	78	68	
External/Internal ratio, 90° abduction (%)	100	105	
RANGE OF MOTION			
Shoulder motion	**Right (Healthy dominant)**	**Left (Injured non-dominant)**	**Side-to-side (°)**
Internal rotation, 45° abduction (°)	70	63	-7
External rotation, 45° abduction (°)	96	83	-13
Internal rotation, 90° abduction (°)	80	80	0
External rotation, 90° abduction (°)	119	110	-9
Abduction (°)	171	160	-11
Adduction (°)	9	15	6
Flexion (°)	198	182	-16
Extension (°)	69	60	-9

considering the option of an arthroscopic surgery in case this last treatment approach would have failed.

Exercise therapy is known to be the most effective treatment to restore shoulder ROM and function in RCRSP [20,51,52,69-71], therefore, considering that the clinical symptoms of the patient in this phase did not considerably impair activities of daily living, it resulted feasible starting a rehabilitative exercise progression with minimal risk. During the first six weeks, in addition to functional and strengthening exercises, NMES+ was combined to the exercise proposal (Table 2). NMES+ training has shown to be effective in restoring muscle size and strength after musculoskeletal disorders [72-75] acting at a neuromuscular level and facilitating spinal excitability [76]. Furthermore, it has been recently demonstrated that an electrical peacemaker stimulus applied to the rotator cuff and periscapular muscles in functional shoulder instability can provide fast and long-lasting benefits when other treatments failed [21,22]. In addition, NMES+ combined with isometric contraction was shown to be effective in restoring external rotation strength and mobility after rotator cuff-repair [77]. Unfortunately, detailed rehabilitation protocols for dosing, electrodes positioning and exercise selection in the application on NMES+ for RCRSP are lacking in the scientific literature. Hence, it was decided to create a protocol based on the scientific evidences for NMES in lower limb rehabilitation and on few further studies on NMES training for shoulder instability, using traditional concentric-to-eccentric exercises with no loads (elastic bands, weights, etc.). Such approach provides the possibility to induce very high-intensity muscle contractions with no need of fast movements and heavy loads, empowering patients to achieve early sub-maximal muscle recruitment, which would be otherwise unattainable [78]. In addition, differently from traditional eccentric contractions, to perform the concentric-to-eccentric transition of the movement (e.g. from external to internal rotation) during NMES+, a greater antagonist muscle activity is required to counteract the voluntary generated force while combined with NMES+. Thus, implementing this exercise therapy, it is possible to generate a higher concentric/(agonist)-eccentric/(agonist-antagonist) muscle work which may be very helpful in the early stages of RCRSP rehabilitation.

Nevertheless, NMES+ was considered as a tool to boost the recovery of muscle strength, volume, and joint mobility in the early rehabilitation, facilitating the execution of a structured exercise program associated with load progression to the patient, since mechanical loading is known to be crucial in restoring the tendon mechanotransduction properties in tendinopathies [26,79-81]. Accordingly, after the first successful period (six weeks) focused on recovering an effective shoulder function, NMES+ was discontinued in favor of active exercises with load progression only.

Isoinertial training was introduced at the sixth week. This training paradigm is based on an external force applied to win the inertia of a heavy wheel [82]. The faster the wheel spins around itself, the more the energy is stored and released, with action velocity as a key element [44]. Such method has been shown to increase the eccentric load during muscle actions [41] and to be effective in building muscle mass and increasing power and strength with similar or better results compared to traditional resistance training [83].

Recent studies have shown that focusing on the eccentric phase only is not sufficient to treat tendinopathies, and that an active concentric phase is needed to complete a tendon rehabilitation program [84]. Therefore, the features of isoinertial training make it an interesting option in the rehabilitation of tendinopathies. Hence, after reaching satisfactory function and motion, powerful contractions by using the isoinertial device were introduced. The subject started performing external/internal rotation exercises with no abduction (Table 3A, 3B) and low inertia (sixth-seventh week), progressing toward abducted external/internal rotation and abduction/adduction movements with high inertia (eight-twelfth week) (Table 4C, 4D). After reaching an almost full active ROM the number of supervised rehab sessions was reduced from two to one per week from the ninth to the twelfth week, and the subject was allowed to return to the gym once a week with a schedule agreed with the rehabilitation staff. The subject was allowed to approach the swimming pool adding a session per week with his team and following a differentiated work aiming at familiarizing with sport-specific skills [54] on the eleventh week.

The overall rehabilitation exercise program (Table 2) followed the principles of exercise and load progression, with the aim of simultaneously improves strength and ROM [85]. The adoption of new exercises along the steps of the whole rehabilitation process was always discussed and approved by the patient.

Before obtaining return to sport clearance, the subject performed a functional test battery to evaluate strength and mobility compared to the healthy and injured shoulder (Table 5). Isometric strength testing for external/internal rotator muscles showed a side-to-side difference within 10% which is considered a cut-off value for return to sport, in addition, the external/internal rotators ratio was comparable to normative values in overhead athletes and swimmers [86,87]. Considering the ROM recovery, the values were comparable to swimmers for dominant and non-dominant arm [88,89].

It was decided to set the exercise proposal with a pain threshold of five out of ten using the 0-10 NPRS [90,91]. Exercise into pain is known to have potential short-term pain relief effect and may help in the reconceptualization and in reducing the catastrophizing of the pain experience [92,93]. Given that, pains with pain-free exercises were alternated to facilitate pain management strategies for the subject.

Both at the beginning and at the end of the rehabilitation period, an MRI scan was performed on the subject (Figure 3). Despite the positive clinical evolution of symptoms throughout rehabilitation, scans did not show substantial changes, underlining the poor correlation between MRI findings and clinical symptoms especially in athletes [94-97]. The overall testing results reached values close to the suggested references for a safe return to athletic performance after shoulder injury [98].

A DASH questionnaire was completed before and after the entire treatment period (June 2019 and June 2020, respectively), showing a considerable improvement moving from the initial score of 47.36% to the final of 14.28%, therefore highlighting a large clinical relevance [99,100].

Conclusion

RCRSP is a very common pathology in overhead athletes and a structured rehabilitative exercise progression with physical activity modification should be considered as the first-line treatment in the rehabilitation approach. NMES+ can be considered as a promising tool to help restoring strength and function in the early stages of rotator cuff rehabilitation. Isoinertial training may support restoring strength and power in the mid- and late-stage of the rehabilitation process with shoulder injuries. This case report is the first study providing a detailed rehabilitation protocol for RCRSP including NMES+ and isoinertial training as part of the exercise protocol. Further future studies are needed to deepen the understanding of these novel rehabilitation approaches and their possible contribution in shoulder rehabilitation.

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