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Non-Surgical Lower-Limb Rehabilitation Enhances Quadriceps Strength in Inpatients with Hip Fracture: A Study on Force Capacity and Fatigue

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Abstract: Measuring muscle fatigue and resistance to fatigue is a topical theme in many clinical research studies. Multi-domain approaches, including electromyography (EMG), are employed to measure fatigue in rehabilitation contexts. In particular, spectral features, such as the reduction in the median frequency, are accepted biomarkers to detect muscle fatigue conditions. However, applications of fatigue detection in clinical scenarios are still limited and with margin for improvement. One of the potential applications of such methodology in clinics concerns the evaluation of the rehabilitation after hip fracture. In this work, 20 inpatients, in the acute phase after hip fracture surgery and with lower limb weakness, performed isometric contractions with their healthy lower limb (quadriceps muscle) and their resistance to fatigue before and after 2 weeks of rehabilitation program was measured. Multi-channel EMG and Maximum Voluntary Contractions (MVC, force) were recorded on five muscle heads. We found that, after performing the same number of repetitions (repetitions pre-treatment: 19.7 ± 1.34; repetitions post-treatment: 19.9 ± 0.36; p = 0.223), MVC improved (MVC pre-treatment: 278 ± 112 N; MVC post-treatment: 322 ± 88 N; p = 0.015) after rehabilitation for most of the patients and fatigue did not change. These results suggest that higher force exertion was performed after rehabilitation, with the same level of fatigue (fatigued muscles pre-treatment: 1.40 ± 1.70; fatigued muscles post-treatment: 1.15 ± 1.59; p = 0.175) after. Results are discussed addressing the potential of multifactorial instrumental assessments for describing patients' status and provide data for clinical decision making.

Keywords: EMG; muscle fatigue; rehabilitation; quadriceps; vastus lateralis; median frequency; isometric contraction

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1. Introduction

During the hospitalization after hip fracture, in the acute care phase, older adults spend the majority of their time in immobility [1]. Hospitalization has negative effects on inpatients, such as muscular weakness and atrophy [2]. These problems especially affect older patients that need a longer time for recovery, which affects their usual daily life activity performance and independence [3]. When a person is bedridden for an extended period of time due to an injury, as is often the case with femur fractures, there is a significant loss of muscle mass and volume in the affected limbs. This loss of muscle mass can lead to a loss of muscle strength up to 40% within the first week of immobilization [4]. It was found that early rehabilitation interventions may induce positive outcomes on such patients, improving motor functionality [5]. However, in order to minimize injury risk and improve clinical practice, recent studies focused on multi-domain assessments and on the determination of the characteristics of the muscles in patients with hip fracture [6]. One of these assessments consists of the study of muscle fatigue, as it provides a quantitative and objective method to detect the capability of a muscle to exert force and resist to loads. In fact, muscle fatigue can be defined as the decline in muscle maximum force during continuous contractions [7]. Multiple concurrent factors contribute to fatigue [8], such as muscle fiber composition, regulation of ions, energy-related and neural factors, and many others. It was observed that motoneurons produce a high frequency signal to gain the maximum contraction, but high frequency signals cannot be sustained for long, and this leads to a reduction in the exerted muscle force. Even if several methods can be used for muscle fatigue detection, such as mechanomyography and near infrared spectroscopy (NIRS) [9,10], surface electromyography (sEMG or EMG) is one of the most used methods to measure fatigue in rehabilitation contexts [11]. In particular, the reduction in features such as the median frequency (MF) or mean frequency [12] are accepted biomarkers to detect muscle fatigue conditions [13] associated with the physiological processes described above.

Many studies have been carried out to detect and investigate muscle fatigue with EMG in several contexts, with a majority of applications related to research laboratories and sports. A variety of detection methods to assess fatigue with EMG signals is available [11,14]. In laboratory applications, EMG provides insights into muscle performance in normal and pathological conditions and has been used to study muscle fatigue in healthy people, showing that resistance to fatigue is firstly influenced by age [15–17]. Recent studies have shown the evolution of medium-term fatigue on the upper-limb of healthy people in isometric conditions [18] and described it effectively with a documented decrease in the median frequency until failure in holding the isometric posture. Moreover, multi-domain approaches have been carried on in order to correlate muscle fatigue with electrodermal activity and heart rate variability in isometric contractions performed by healthy subjects [19]. The EMG measurements provide a non-invasive way to monitor the muscle activity of patients also in intensive care units (ICU), helping clinicians to quantify muscle activity and recovery of patients, guiding the rehabilitation process [20]. Even though in hospitals the assessment of muscle fatigue based on EMG monitoring has been rarely used for practical applications, some studies are available. Muscle activity has been monitored in ICU patients during cycling activities, demonstrating the feasibility of EMG assessment and its potential in rehabilitation evaluation [21]. EMG has been used also for assessing diaphragm function in patients who are mechanically ventilated [22]. Moreover, muscle fatigue analysis has been used to compare stroke patients at different stages [23] and in observational studies to compare patients to healthy participants in order to evaluate the feasibility of using EMG in ICU [24]. These studies showed measures that provide general information of muscle activity; however, the assessments are usually not exploited to directly guide the early rehabilitation intervention. To our knowledge, few studies have investigated muscle fatigue using EMG in patients at the bed side, especially with multi-domain approaches. Only some preliminary studies have been conducted for assessing patient rehabilitation with EMG and NIRS [25].

Muscle fatigue can be an indicator of motor recovery for inpatients and it can be used to assist the physical therapist in implementing a patient-tailored exercise prescription [24] and provides feedback on training activity and motor recovery [20]. Patients with hip fracture are usually old and frail subjects that need time after orthopedic surgery to restore their mobility [26]. Therefore, rehabilitation intervention for stimulating muscles also during hospitalization may have beneficial effects on the motor recovery and quality of life of older inpatients [27]. However, the effects of early rehabilitation for inpatients that underwent an orthopedic surgery have been rarely assessed in the literature with muscle fatigue. In this scenario, many studies have proposed a multi-domain assessment for patients with orthopaedical or neurological diseases [6,28] whereas there are very few instrumental measurements of fatigue in patients with motor disability. In this study, EMG data are coupled with force evaluation for a description of the course of rehabilitation of inpatients, as a preliminary outcome of a multi-domain approach also including Time Domain (TD) NIRS, and force and measurements. Therefore, the purposes of our study were twofold and expand upon recently adopted approaches [24]. First, we assessed the feasibility of collecting EMG on inpatients to measure their recovery in the framework of a multi-domain evaluation, and second, we investigated the variation in muscle fatigue during isometric submaximal contractions comparing the performances of a group of hospitalized patients, before and after a rehabilitation therapy.

2. Materials and Methods

2.1. Participants

For this study, 20 inpatients (79.5 ± 6.52 years) admitted to the Rehabilitation Department for rehabilitation program following hip fracture were enrolled. Exclusion criteria were the presence of neoplastic and other major neurological/psychiatric, cardiovascular, or pulmonary disorders. The non-injured leg was evaluated by superficial EMG during voluntary isometric contractions. The choice of prioritizing the non-injured leg was firstly determined by the nature of the injury (femur fracture) that prevents the application of heavy rehabilitation tests to the injured leg immediately after surgical operation. Moreover, the non-injured leg can be considered as a reference for the injured leg [29]. Other studies provide information about the importance of rehabilitation after a femur fracture, the effects of immobilization on muscle strength and mass, and the importance of addressing the overall musculoskeletal health during the rehabilitation process [30]. Therefore, in order to maximize the success of rehabilitation efforts, it is important to prioritize the non-injured leg initially and to work to maintain or improve its strength and mobility while also addressing the injury itself. In this way, the person's overall musculoskeletal health can be improved, which will in turn help to facilitate their recovery and overall quality of life [31].

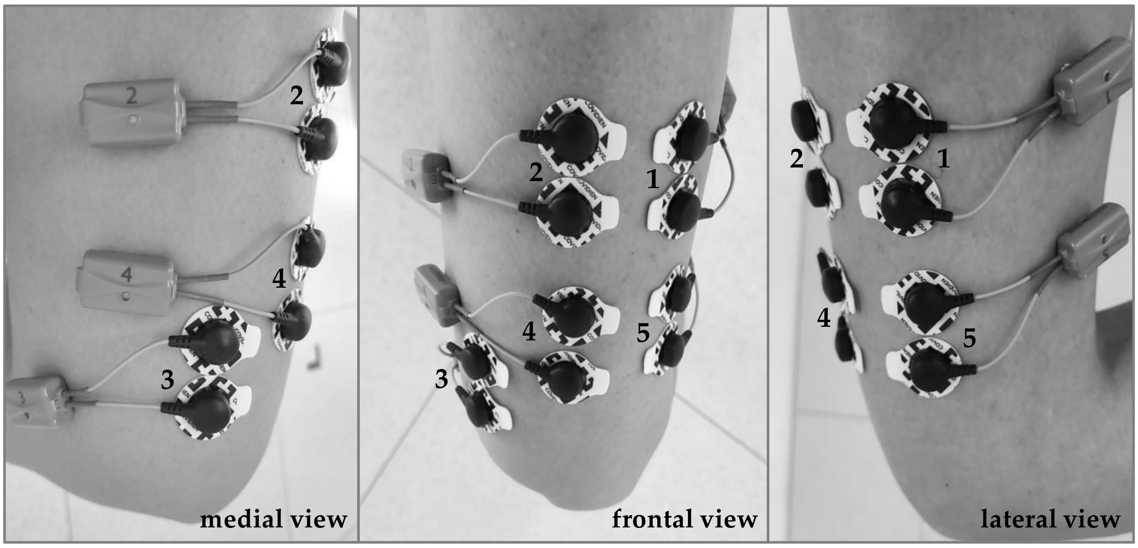
This study was approved by the Regional Ethical Committee Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico—Milano Area B (protocol n°14386/2015) and conducted in accordance with the Declaration of Helsinki. All subjects signed their informed consent.

2.2. Experimental Set up and Design

The experimental set-up is portrayed in Figure 1. Patients were seated on a custom chair, allowing us to fix the knee angle at 120° and to guarantee their safety and comfort. The evaluation was performed on the non-injured leg. Firstly, the traction force was measured by a strain gauge positioned below the leg holder in order to compute the maximum voluntary contraction (MVC) during an isometric contraction of the quadriceps muscle. The MVC was calculated as the maximum of three consecutive trials so that the effective MVC was considered, similar to other studies [32,33]. After a period of 60 s of baseline, patients were required to perform 20 isometric contractions at the 80% of MVC with a confidence interval of ±10%. A visual real-time feedback of the exerted force and goal threshold was given to the patients. Each repetition consisted in 10 s of continuous contraction followed by 5 s of relaxation. A recovery period of 300 s was given at the end of the exercise. This protocol was conceived considering previous applications that selected similar evaluation sessions as a reasonable trade-off between fatigue elicitation and clinical practical applicability. Previous studies showed that quadriceps muscle underwent fatigue in protocols based on repeated contractions in timings similar to those adopted in this study [34,35]. The MVC was acquired at two different time-points: PRE—at 6–8 days after the femur fracture and around 3 days after the surgery; POST—at 15 days after the PRE. Patients followed a daily physiotherapy rehabilitation program between PRE and POST time-points. The acquisition rate was 200 Hz. Torque and EMG signal were acquired during the whole exercise. The beginning and the end of each contraction were identified with an auditory stimulus (Presentation®, Neurobehavioral Systems Inc.). All the acquisitions and stimuli were synchronized.

Figure 1. Set up for the experiment.

During the trials, 5 EMG bipolar probes (EMG system: wireless Cometa 16-channels, Milan, Italy) were placed on the quadriceps muscle according to a multisite muscle recording protocol inspired by previous applications in the field [36,37], through Ag-Cl electrodes on the following anatomical landmarks: vastus lateralis (proximal), vastus lateralis (distal), vastus medialis, rectus femoris (proximal), and rectus femoris (distal). Electrode placement is shown in Figure 2. This multi-channel mapping was chosen to account for multiple muscle heads contracting during isometric tests, since it is not a priori possible to address all muscle torque at knee level to a single muscle head.



1. Vastus Lateralis (proximal head) 2. Rectus Femoris (proximal head) 3. Vastus Medialis
4. Rectus Femoris (distal head) 5. Vastus Lateralis (distal head)

Figure 2. Positioning of EMG electrodes. Vastus lateralis (proximal head), vastus lateralis (distal head), vastus medialis, rectus femoris (proximal head), and rectus femoris (distal head).

2.3. Rehabilitation Treatment

The participants in this study were enrolled in a standard rehabilitation program that involved physical therapy and early mobilization. The physical therapist provided the exercise program, which was prescribed by physician specialists. These goals of rehabilitation program addressed leg edema, quadriceps control, hip abduction strength, and a normalization of gait.

Each patient followed a daily program of 60 min of physical therapy in a day (possibly in 2 sessions), described in detail in Figure 3. Following surgery, patients began with ankle pumps to perform dorsiflexion and plantarflexion of the ankle. Knee extension strength training of the fractured limb was found to be feasible when initiated in the acute phase. The primary objective of these exercises was to enhance muscle strength and improve control of the limb, especially the gluteal and quadriceps muscles. Early mobilization included a series of activities such as getting in and out of bed, sit-to-stand, sitting from a chair with arms, and walking with the aid of a mobility device. The program was a dynamic incorporation of weight bearing progression, gait training with an assistive device, and initiation of lower extremity isometrics, range of motion (ROM) activities, physical therapy modalities, stretching, progressive resistive exercises, balance, proprioception activities, and conditioning.

2.4. Signal Processing and Outcome Measures

The main acquisition outcomes were the MVC recorded with a dynamometer, the number of inspected repetitions from each subject and the Median Frequency calculated from the EMG signal. All the parameters were computed in the PRE (before rehabilitation) and POST (after rehabilitation) therapy sessions. EMG data were sampled at 1 kHz and band-pass filtered (20–450 Hz). A double threshold algorithm [38] was used for signal segmentation and employed to detect EMG activation phases. Each epoch of contraction, having nominal time length of 10 s, was subdivided into 2 s time windows. For each subject, we computed the median frequency (MF) separately for all the 20 contractions performed in each session, in each of the 2 s time windows. We then computed the mean MF for each epoch of contraction (each one composed of 5 time windows). Lastly, we performed a linear regression analysis by interpolating the progression of the mean MF in time. Positive fatigue detection was considered when the slope m of the linear regression was negative (indicating a shift towards lower frequencies in the spectrum) and $m < -0.5$ Hz/*epoch*. When m was below this value, we considered that muscle under the effect of fatigue—corresponding to reasonable median frequency drop already documented in the literature [32,39] (considering 20 repetitions, this choice corresponds to a mean lowering of about 10 Hz). Consequently, every muscle for each subject was assigned with a binary value (fatigue/no fatigue). However, since the choice for m is arbitrary, we also repeated the analysis with other reasonable threshold values (-0.3 Hz/*epoch*; -0.4 Hz/*epoch*; -0.6 Hz/*epoch*; -0.8 Hz/*epoch*). The linear regression was performed for all muscles and all subjects/acquisitions.

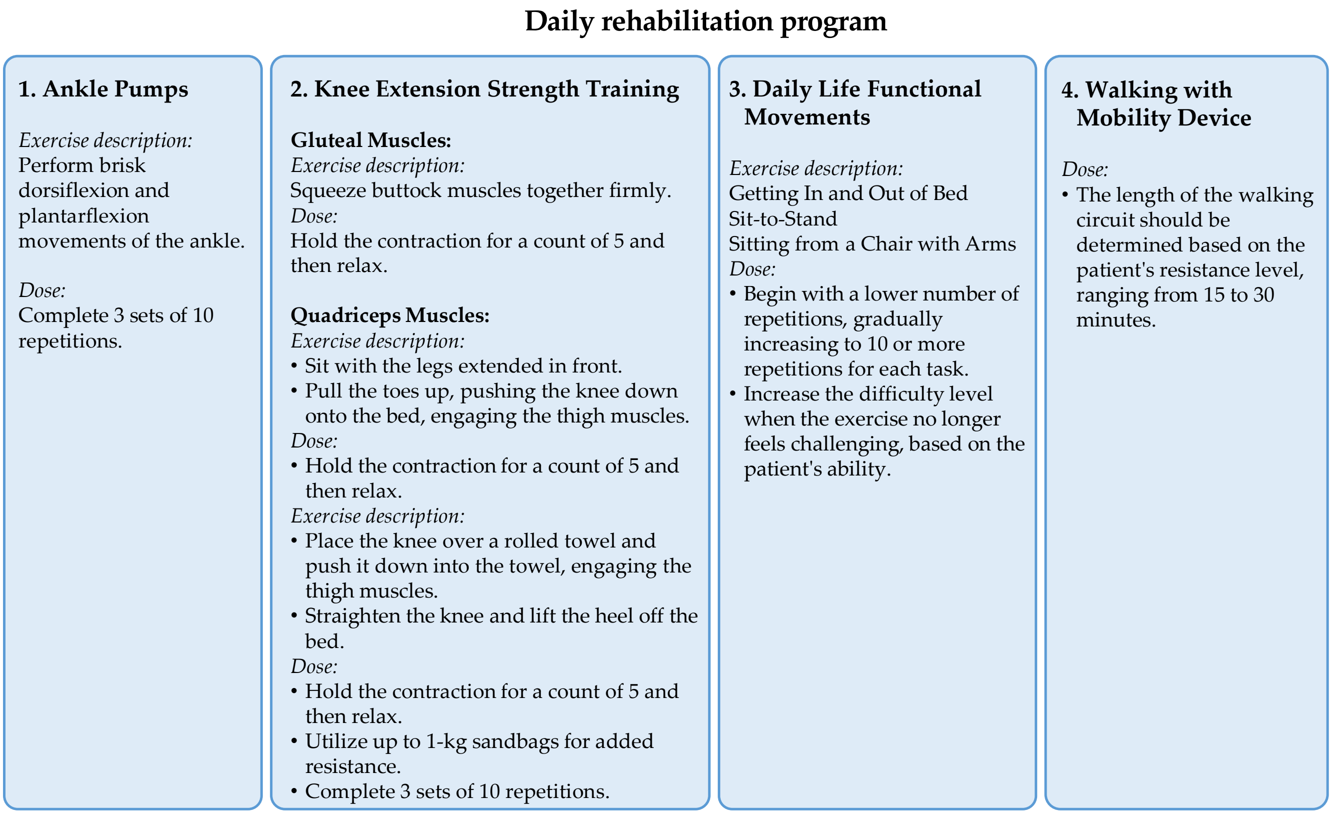


Figure 3. Description of the daily rehabilitation program for patients with hip fracture. The standard rehabilitation program involved a daily schedule with specific load normative. The program consisted of two sessions, a morning session and an afternoon session. Each session lasted 30 min, totaling 60 min of physical therapy per day. The daily program was designed to be conducted six days a week.

2.5. Statistics

After checking for normality, a *t*-test was performed on the MVC measured on three trials for each subject, comparing PRE and POST therapy values, to evaluate the effects of rehabilitation on MVC. In the same way, a *t*-test was performed in order to compare the number of repetitions PRE and POST therapy. To measure modifications in muscle fatigue using EMG, we compared the number of EMG channels showing muscle fatigue PRE and POST therapy for each subject. Considering the ordinal nature of this variable, we used a non-parametric *Mann–Whitney U* test. The significance value was set to 0.05 for all the statistical tests and Bonferroni corrections were used to limit the chance of type I error per comparison. When tests rejected the null hypothesis, to verify the reliability of the results, we computed the achieved statistical power with GPower 3.1.9.7 software (Heinrich Heine University, Dusseldorf, Germany).

3. Results

3.1. MVC

In Table 1, the MVC is reported for all the subjects. After Bonferroni correction, the *t*-test indicated that MVC_{POST} was higher than MVC_{PRE} (322 ± 88 N vs. 278 ± 112 N, p = 0.015). For MVC (force), with our data we had effect size = 0.59 that corresponded to statistical power = 0.82. In 15/20 patients, MVC increased. On two patients, there was a session-specific decrease, probably related to subjective status. We conclude that at the end of the rehabilitation period, MVC in the group of patients significantly increased. This finding also implies that their exercise was tuned on higher level of requested force in the POST session.

Table 1. Maximum MVC (N) and number of repetitions (N REP) measured in the pre-rehabilitation and post-rehabilitation sessions. The MVC value is the maximum recorded with the dynamometer across 3 trials per session. ^ excluded from statistical analysis as outlier subject. * statistically significant difference.

	MVC_{PRE} (N)	MVC_{POST} (N)	N REP $_{PRE}$	N REP $_{POST}$
S1	300	290	20	20
S2	230	272	20	20
S3	240	455	20	19
S4	268	189	20	20
S5	660 ^	346 ^	20	20
S6	170	330	20	20
S7	141	196	20	20
S8	326	413	20	20
S9	211	216	20	20
S10	226	349	20	20
S11	568	458	14	19
S12	275	366	20	20
S13	201	221	20	20
S14	210	240	20	20
S15	283	326	20	20
S16	550	400	20	20
S17	247	329	20	20
S18	252	323	19	19
S19	301	438	20	20
S20	306	433	20	20
Mean	278	322	19.7	19.9
Std	112	88	1.34	0.36
p		0.015 *		0.223

3.2. Number of Repetitions

In Table 1, the number of evaluated repetitions (N REP) is reported for all the subjects. The *t*-test indicated that N REP_{POST} was not different from N REP_{PRE} (19.7 ± 1.34 repetitions vs. 19.9 ± 0.36 repetitions, p = 0.223). For 19/20 patients, the number of repetitions evaluated was unchanged. We conclude that the number of repetitions performed was the same when comparing PRE and POST.

3.3. Multi-Channel EMG and Muscle Fatigue

In Figure 4, a typical EMG time course is shown for the five muscle heads recorded; a contraction had a nominal time length of 10 s, with nominal pauses of 5 s. In Figure 5, we show an example of regression for MF. A regression line connects the MF values in following epochs. This signal was used to detect fatigue.

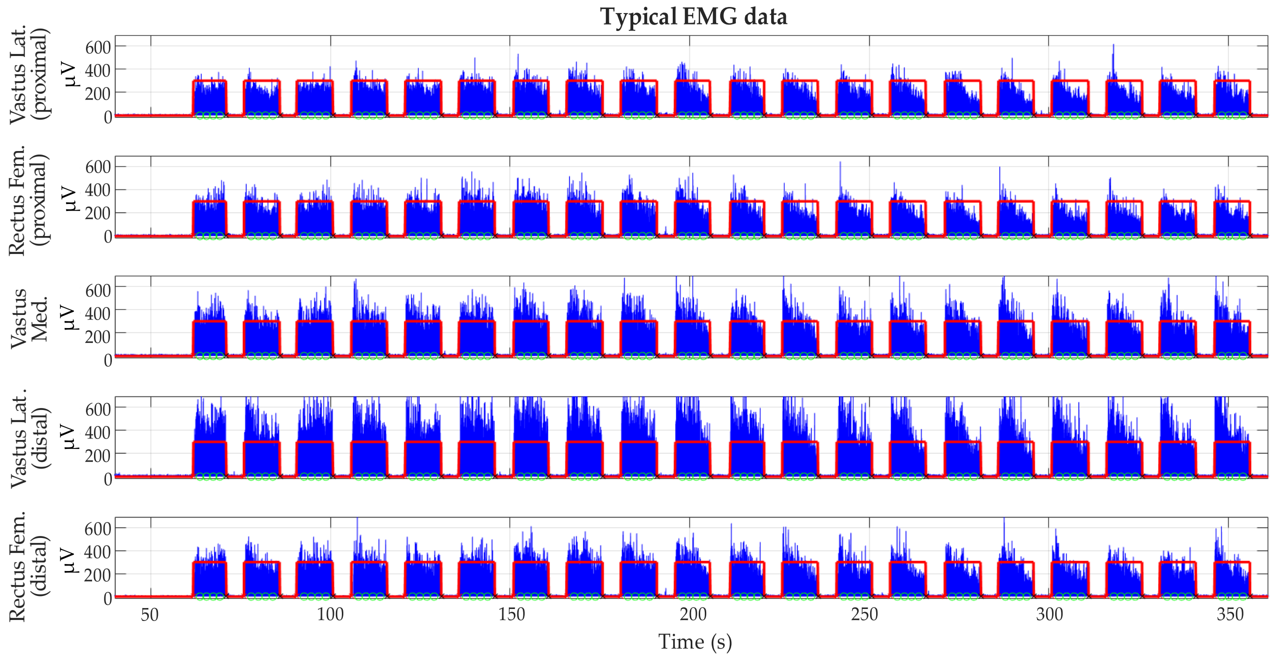


Figure 4. Typical time courses from EMG measurements. EMG raw signal is in blue; red squares indicate the phase segmentation (contraction—no contraction).

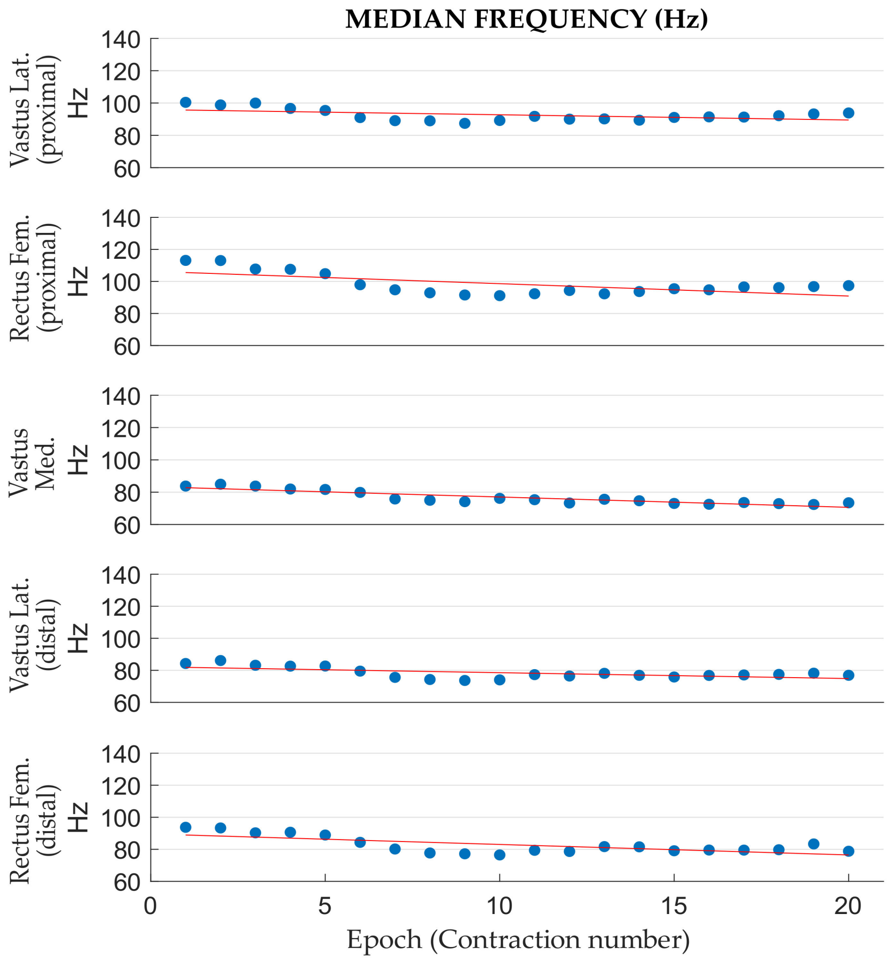


Figure 5. Typical time courses for median frequency. The *m* (angular coefficient) of the regression line was used to determine the detection of fatigue.

In Figure 6, the *m* coefficients for MF are reported for each subject and muscle before the rehabilitation (gray) and after the rehabilitation (light blue). When *m* is positive, MF is increasing during contractions; when *m* is negative, MF is decreasing; and fatigue may be detected if $m < -0.5$ Hz/*epoch*.

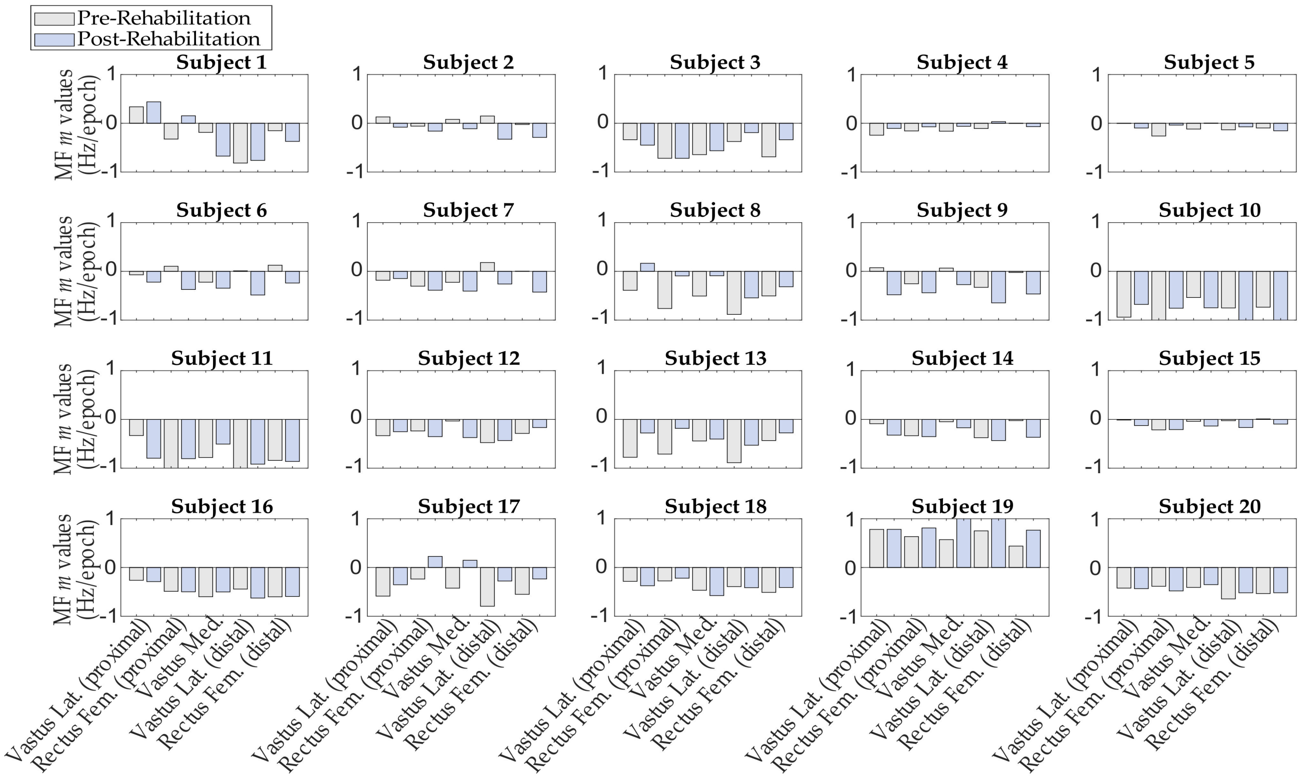


Figure 6. *m* coefficients indicate the increase (positive *m*) and the decrease (negative *m*) of the median frequency of each muscle. Values are compared between pre-therapy phase (gray) and post-therapy phase (light blue).

Table 2 shows the muscle heads in fatigue condition (indicated by 1) and those that are not in fatigue conditions (indicated by 0). The non-parametric test showed that there was not a significant difference in the number of fatigued muscles PRE and POST therapy ($p = 0.175$), with a slight tendency towards fatigue reduction, but visible only on few patients. This result is achieved with a simultaneous increase in the MVC exerted by each subject. Even with different thresholds for detecting fatigue, statistical tests do not show statistically significant differences (data not reported).

Table 2. Muscles in fatigue condition and number of fatigued muscle heads for each of the subjects in PRE and POST therapy. Fatigued muscles are identified with 1, muscles with no fatigue with 0.

	PRE						POST					
	Vastus Lat. (prox)	**Rectus Fem. (prox)**	**Vastus Med.**	**Vastus Lat. (dist)**	**Rectus Fem. (dist)**	**Total**	**Vastus Lat. (prox)**	**Rectus Fem. (prox)**	**Vastus Med.**	**Vastus Lat. (dist)**	**Rectus Fem. (dist)**	**Total**
S1	0	0	0	1	0	1	0	0	1	1	0	2
S2	0	0	0	0	0	0	0	0	0	0	0	0
S3	0	1	1	0	1	3	0	1	1	0	0	2
S4	0	0	0	0	0	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0	0	0	0	0	0
S6	0	0	0	0	0	0	0	0	0	0	0	0
S7	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	1	1	1	1	4	0	0	0	1	0	1
S9	0	0	0	0	0	0	0	0	0	1	0	1
S10	1	1	1	1	1	5	1	1	1	1	1	5
S11	0	1	1	1	1	4	1	1	1	1	1	5
S12	0	0	0	0	0	0	0	0	0	0	0	0
S13	1	1	0	1	0	3	0	0	0	1	0	1
S14	0	0	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0	0	0
S16	0	0	1	0	1	2	0	0	1	1	1	3
S17	1	0	0	1	1	3	0	0	0	0	0	0
S18	0	0	0	0	1	1	0	0	1	0	0	1
S19	0	0	0	0	0	0	0	0	0	0	0	0
S20	0	0	0	1	1	2	0	0	0	1	1	2
Mean						1.40						1.15
Std						1.70						1.59
p												0.175

4. Discussion

4.1. Summary of the Main Results

We found that fatigue assessed with EMG changed only slightly after rehabilitation, with a non-significant tendency toward reduction; however, at the same time, MVC improved after rehabilitation for most of the patients, suggesting that higher force could be exerted, with no fatigue increase and performing the same number of repetitions. These results show a partial increase in the performances of inpatients, fostering the need of instrumental approaches applied to clinical practice for a deep understanding of the rehabilitation process.

4.2. Results Interpretation

EMG-based metrics such as mean frequency or median frequency are commonly used biomarkers for measuring muscle fatigue in patients and athletes [12,13]. Using EMG-related measurement for inpatients has already proven to be a valuable methodology. In fact, the onset of fatigue has been already observed in previous studies, reporting that during dynamic contractions in healthy younger and hospitalized patients, there was a statistically significant difference between MF at initiation and termination of contractions, indicating that subjects' muscles did truly fatigue [24].

In this study, we found very similar fatigue levels before and after a 2-weeks rehabilitation intervention, even when testing different thresholds for fatigue detection. While the choice of the threshold impacts on the number of EMG channels showing muscle fatigue, our analysis showed that, when comparing PRE and POST therapy findings, this induced no alteration of statistical tests, suggesting that the results are inherent to the dataset and are not related to the adopted threshold for fatigue. However, similar fatigue patterns are coupled with higher MVC, which translates to more demanding physical training during our evaluation trial. It also suggested that patients underwent functional improvement as higher MVC is not associated with more muscle fatigue, thus patients could hold significantly higher forces with no significantly higher fatigue levels.

A distinguishing feature of our study was that five muscle heads were monitored simultaneously. While the exercise was designed to involve as a primary muscle the vastus lateralis (proximal head), we immediately noted that the whole quadriceps muscle was involved in force exertion. A multi-channel recording might be useful to detect if, for various reasons (positioning, partial adherence to the protocol, compensatory strategies, etc.), subjects were experiencing fatigue, but on other muscle heads, which it happened indeed. In fact, muscle heads of quadriceps are non-uniformly activated during fatiguing exercises [38,40].

A relevant result that we found was that for some subjects, fatigue was not detected in the measured muscle heads. This can be explained by admitting that some patients might not have exerted their maximum MVC, or because of their good training level. Non-adherence to the exercise guidelines was limited as multiple trials were performed and graphical and vocal feedback were given by sanitary operators and experimenters to motivate patients. It is also possible that for some patients the exercise was not challenging enough. Lastly, while patients were in general compliant to the task, their motivation and effort could not be perfectly uniform throughout the trials and the sessions.

In general, it was found that EMG metrics did not improve (i.e., fatigue was not reduced). This is, however, explainable with the increased MVC: while fatigue did not increase, functional performance was higher. However, it may also indicate that a 2-week protocol could not be long enough to detect significant changes on EMG-based metrics. The results might also be related also to the training level of the patient before the hip fracture. The acquisition protocol was based on MVC to provide challenging conditions to patients; however, if MVC in the post-rehabilitation was set a priori equal to the pre-rehabilitation value, it is likely that muscle fatigue might decrease in more patients as the exercise would be less challenging. Our results could be the basis for a selection of the length of clinical protocols to maximize recovery reducing hospitalization times and consequently costs and unpleasant time spent in the hospital for patients.

4.3. Application to the Clinics

Our results give practical suggestions for clinical practice and open the way to novel research topics and scientific questions. The use of instrumented multi-domain measurements (such as EMG, force, NIRS, kinematics) might help in understanding the complex process underlying motor recovery in rehabilitation [28]. Multi-domain approaches, in particular, may help in providing a wide spectrum of assessments that might be complementary or provide information of different nature [41,42]. Future works will contextualize the presented data with a broader view also including the acquired TD NIRS data for a complete multi-domain approach aiming at characterizing patients' motor functionality.

Preliminary studies showed that results from a multi-domain approach may contribute to clinical evaluation and decision-making process. For example, using measurements of force, EMG and nerve stimulation, individuals with intellectual disability showed different neuromuscular profiles and recovery kinetics that have to be considered during prescription of training programs [43]. Moreover, both muscle activation patterns and kinematics are altered during fatigue [44] and they should be monitored during fatiguing exercises and rehabilitation in order to prevent injuries related to fatigue [45,46].

4.4. Limitations

In this study, we showed the feasibility of EMG employment for fatigue detection and motor recovery evaluation for inpatients. However, the reduced sensitivity to deeper structures leads to some limitations. Indeed, the activity of deeper muscles that may contribute to the task could not be measured by surface EMG. This problem can be addressed using more invasive procedures or with EMG array-based acquisition and processing techniques that can identify the discharge of multi-channel action potentials by individual muscle units. Alternatively, some works proposed a non-invasive methodology for muscular fatigue detection based on electrodermal activity (EDA) and heart rate variability (HRV) [19] that may be related to EMG and may provide a multi-parameter analysis allowing a complete characterization of the patient. Furthermore, our study considers only the median frequency as biomarker of muscle fatigue, as it is the standard and most used method in the field. Other measures, such as root mean square (RMS) or other spectral features of the EMG signal and NIRS can be included in future work that may provide further insight on muscle fatigue and show correlations among multiple domains of analysis.

Moreover, since the hip fracture is an accidental event, we could not compare the results to the performance of the patient before the event. Patients may have had a different training level that may be correlated to the MVC increase during rehabilitation and also to fatigue development.

Finally, for detecting muscular fatigue and perhaps provide a comprehensive analysis of the patient's condition, we should consider tools specifically designed to assist this vulnerable population once frailty has been identified. Given that frailty is the cumulative effect of various conditions and is the most significant factor in regaining independence, addressing this gap is crucial [47,48].

5. Conclusions

In this work, we assessed the effects of a 2-week rehabilitation therapy for inpatients, measuring MVC and muscle fatigue with EMG. We showed the feasibility of the combined employment of force and EMG for the evaluation of the rehabilitation in a clinical setting, and we found that inpatients can exert higher forces after a "relatively short" rehabilitation, with the same level of fatigue as measured with EMG sensors. Future applications will include the expansion of such results to a wider cohort of subjects and inclusion of multi-domain approaches for clinical decision making.

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