

Does Standard Physical Therapy Increase Quadriceps Strength in Chronically Ventilated Patients? A Pilot Study

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Objectives: Physical therapy is standard care for mechanically ventilated patients, but there is no evidence, using nonvolitional, objective measurements, that physical therapy increases muscle strength in this population. The present study tested the hypothesis that 2 weeks of standard, conventional physical therapy provided at a ventilator weaning facility would increase quadriceps strength in mechanically ventilated patients.

Design: Prospective observational study.

Setting: Ventilator weaning unit.

Patients: Patients who were transferred from an acute care hospital because of failure to wean from mechanical ventilation and who were receiving physical therapy as prescribed by facility staff.

Interventions: None.

Measurements and Main Results: We employed a novel, nonvolitional objective technique, quadriceps twitch force generation in response to femoral nerve magnetic stimulation, to assess leg strength before and after 2 weeks of conventional physical therapy. The duration and specific exercises provided to patients were also recorded. In a subset of patients, we measured muscle activation intensity using wireless electromyogram recordings. Indices of respiratory function (maximum inspiratory pressure generation and the rapid shallow breathing index) were also assessed. Patients' responses to 2 weeks of physical therapy were poor; on average, quadriceps twitch fell by -1.02 ± 0.71 Newtons. Neither physical therapy duration nor specific forms of exercise were identified to positively impact quadriceps twitch. Electromyogram

recordings indicated that during training, muscle activation was poor. Consequently, therapists spent substantial time performing exercises that elicited little muscle activation. Physical therapy did not improve respiratory function.

Conclusions: Standard physical therapy delivered in a ventilator weaning facility failed to improve quadriceps leg strength in a majority of mechanically ventilated patients. The fact that mechanically ventilated patients fail to achieve high levels of muscle activation during physical therapy provides a potential explanation as to why physical therapy may often be ineffective. We speculate that use of novel methods which increase muscle activation during exercise may improve responses of mechanically ventilated patients to physical therapy. (*Crit Care Med* 2020; 48:1595–1603)

Key Words: critical illness myopathy; electromyograms; muscle activation during exercise; physical therapy during mechanical ventilation; quadriceps twitch force generation; quadriceps weakness

Physical therapy (PT) is standard of care for mechanically ventilated (MV) patients (1–3) and is thought to prevent the negative effects of critical illness and immobility, improving outcomes (4–6). Precisely how much PT patients should receive, however, remains unclear. A recent large randomized controlled trial found that intensive, early PT (“early mobilization”) did not improve any index of acute or chronic patient outcomes over standard, conventional PT (7), suggesting that standard PT regimens may be adequate for these patients (8).

A major pitfall of prior work is that no study has employed nonvolitional, purely objective indices of muscle function to determine if standard PT increases muscle strength in MV patients (9). Furthermore, most standard PT regimens incorporate various combinations of exercises (resistance training, range of motion, sitting/standing at the bedside, walking while MV, and arm/leg cycle ergometry), but no one knows which forms and durations of exercise are best for improving muscle function. As a result, there are important

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unanswered questions regarding how best to provide PT to MV patients (6, 10, 11).

The purpose of this prospective observational study was to test the hypothesis that 2 weeks of standard PT improves quadriceps strength in MV patients. We measured quadriceps strength using a recently described novel technique, magnetic femoral nerve stimulation evoked quadriceps twitch (QuadTw) force generation (12), which provides a purely objective, non-volitional determination of quadriceps muscle force generation. In a subgroup of patients, wireless electromyograms were used to objectively assess levels of muscle activation. These latter data were analyzed to determine which exercises produced the highest leg muscle activation during PT sessions. Finally, since some studies suggest that PT improves respiratory function, we also measured maximum inspiratory pressure ($P_{i_{max}}$) generation and the rapid shallow breathing index (RSBI).

MATERIALS AND METHODS

Protocol

Patients were recruited from the long-term care ventilator facility at Rockcastle Regional Hospital and Respiratory Care Center, Mount Vernon, KY. It is important to note that medical systems in Kentucky usually keep patients in traditional acute care ICUs for 1–3 weeks and then transfer them to units such as the Rockcastle ventilator facility once they are stable. As a result, these patients had recovered from initial infections (none were on antibiotics at the time of study), had received tracheostomies because they were unable to be weaned from MV in the acute care hospital setting (ICU), and were subsequently transferred to Rockcastle Regional Hospital Respiratory Care Center for further weaning and physical rehabilitation. Once transferred to Rockcastle from the acute ICU, these patients were weaned from sedation, placed on oral and/or enteral feedings, and were capable of participating in PT.

The Rockcastle Institutional Review Board (IRB) and the University of Kentucky IRB approved the study. Informed consent was obtained from all patients. Nineteen of 21 consenting patients completed the protocol. Day 1 measurements included: baseline QuadTw (12), quadriceps thickness, $P_{i_{max}}$ (13), the RSBI (14, 15), and the Functional Independence Measurement (FIM) score (16). Rockcastle staff physical therapists logged durations, types, and intensities of exercise patients received for each therapy session over the next 2 weeks. On day 15, measurements of QuadTw, muscle size, $P_{i_{max}}$, and RSBI were repeated. Ventilator weaning and nutrition regimens were recorded for each patient. Chart reviews provided demographic information (age, gender), diagnoses, and medications.

Inclusion and Exclusion Criteria

Patients were included if they were receiving MV via tracheostomy, medically stable, alert, and capable of performing PT. Patients were excluded if the attending physician thought the patient was unstable, or if the patient required greater than or equal to 0.6 F_{IO_2} or greater than or equal to 10 cm H_2O positive end-expiratory pressure, had a cardiac pacemaker or

defibrillator, preexisting neuromuscular disease, was pregnant, or terminal.

Physical Therapy

As this was a prospective, observational study to assess the effects of community-based PT on quadriceps muscle strength, we deliberately did not alter or in any way influence the facility-prescribed PT regimen throughout this study. As a result, subjects received the standard, conventional forms of PT employed at the Rockcastle Ventilator Unit, with the specific exercise paradigm used for each individual patient chosen by the facility staff.

Therapists recorded the modes of exercise delivered for each PT session, as well as the duration of each individual exercise, the muscles targeted, and the intensity of each treatment. Therapists also estimated the patients' overall physical performance by answering the component questions in the FIM (16).

Physical therapists were asked to estimate initial QuadTw after the first PT session as a percentage of normal for a healthy individual. On day 15, therapists estimated the percent change in QuadTw in response to 2 weeks of PT. Therapists were blinded to QuadTw measurements for the duration of the study so as not to bias estimates of initial or final force.

Measurement of Quadriceps Twitch Strength

QuadTw was measured using the method of Laghi et al (12) with minor modifications (for details, see **Supplemental Data**, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>) (12, 17, 18). The average force of the three best twitches in response to 100% field stimulation was designated as the QuadTw force.

Muscle Size

Quadriceps thickness was determined using ultrasound as previously described (19, 20) (for details, see **Supplemental Data**, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>).

Respiratory Parameters

$P_{i_{max}}$ was recorded as previously described (21) (for details, see **Supplemental Data**, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>). For assessment of the RSBI, the patient was removed from ventilatory support with the total breaths and minute ventilation recorded for 1 minute. This information was used to calculate the RSBI.

Quadriceps Normalized Integrated Electromyogram

Since QuadTw did not improve after 2 weeks of PT in the first 10 patients, we recorded leg electromyograms during PT in the next nine subjects. A BIOPAC system (BIOPAC Systems, Goleta, CA) attached to a laptop computer was used to record electromyogram tracings from four muscles (rectus femoris, vastus lateralis, tibialis anterior, and gastrocnemius) in the right leg. Electrodes were placed prior to PT and recordings made for all exercises during the session. At the end of the sessions, three Babinski reflexes were elicited which produced electromyogram

activation in the four leg muscles from which surface electromyograms were being recorded. Electromyogram magnitude was quantified using the BIOPAC electromyogram analysis program to rectify and integrate electromyogram signals (i.e., to generate a voltage-time integral). Babinski reflex signals were also integrated and the results from the three Babinski reflexes were averaged. Integrated electromyogram activities were normalized by dividing the total integrated electromyogram signal for a given exercise by the Babinski reflex integrated electromyogram signal. For the quadriceps, we termed this parameter the Quadriceps Normalized Integrated electromyogram activity index, that is, the Quadriceps Normalized Integrated Electromyogram (QNIEMG) level. Staff PT and subjects were blinded to all electromyogram recordings.

Statistical Analysis

Two-tailed *t* tests were used to compare normally distributed variables before and after PT. For non-normal data distributions, the Mann-Whitney rank-sum test was used to compare variables before and after PT. For comparing two variables, linear regression analysis was used. A *p* value of less

than 0.05 was taken as indicating statistical significance for comparisons.

RESULTS

Baseline Patient Characteristics

Primary patient diagnoses and medication usage are provided in **Supplemental Table 1** (Supplemental Digital Content 2, <http://links.lww.com/CCM/F721>) and **Supplemental Table 2** (Supplemental Digital Content 3, <http://links.lww.com/CCM/F722>). We also reviewed patients' charts to assess nutritional intake. We found that patients had an average daily caloric intake of $1,680 \pm 58$ calories (i.e., 22.7 ± 1.7 cal/kg/d) and an average daily protein intake of 87 ± 3 g (i.e., 1.19 ± 0.09 g/kg/d).

On day 1, QuadTw was recorded in all patients. QuadTw increased as magnetic field strength increased from 60% to 90% of maximum, with force plateauing when field strength increased from 90% to 100% (representative of individual subject **Fig. 1A**, mean data for all patients in **Fig. 1B**); supra-maximal activation of the femoral nerve 100% field strength was obtained in all patients. Baseline QuadTw linearly correlated

with the initial FIM score (**Fig. 1C**) (FIM score = $64.806 + [0.950 \times \text{QuadTw}]$; $r = 0.542$; $p = 0.016$). Baseline QuadTw also correlated linearly with quadriceps thickness (**Fig. 1D**) (thickness = $2.377 + [0.0403 \times \text{QuadTw}]$; $r = 0.818$; $p < 0.001$), indicating that muscle strength was a function of muscle size for baseline measurements.

Physical Therapy Effects on QuadTw

Patients' response to standard PT was poor. Specifically, QuadTw did not change appreciably over 2 weeks in 13 patients (defined as the final QuadTw level remaining within 1 Newton [N] of the initial value), increased slightly in two patients (increases of 1.1 and 1.7 N), and decreased in four patients (declines of 1.5, 2.0, 5.7, and 12 N). The median value for QuadTw was 3.2 N (25–75% CI of 1.4–8.8 N) for initial testing and was 3.1 N (25–75% CI of 1.4–8.9 N) for final testing ($p = 0.20$;

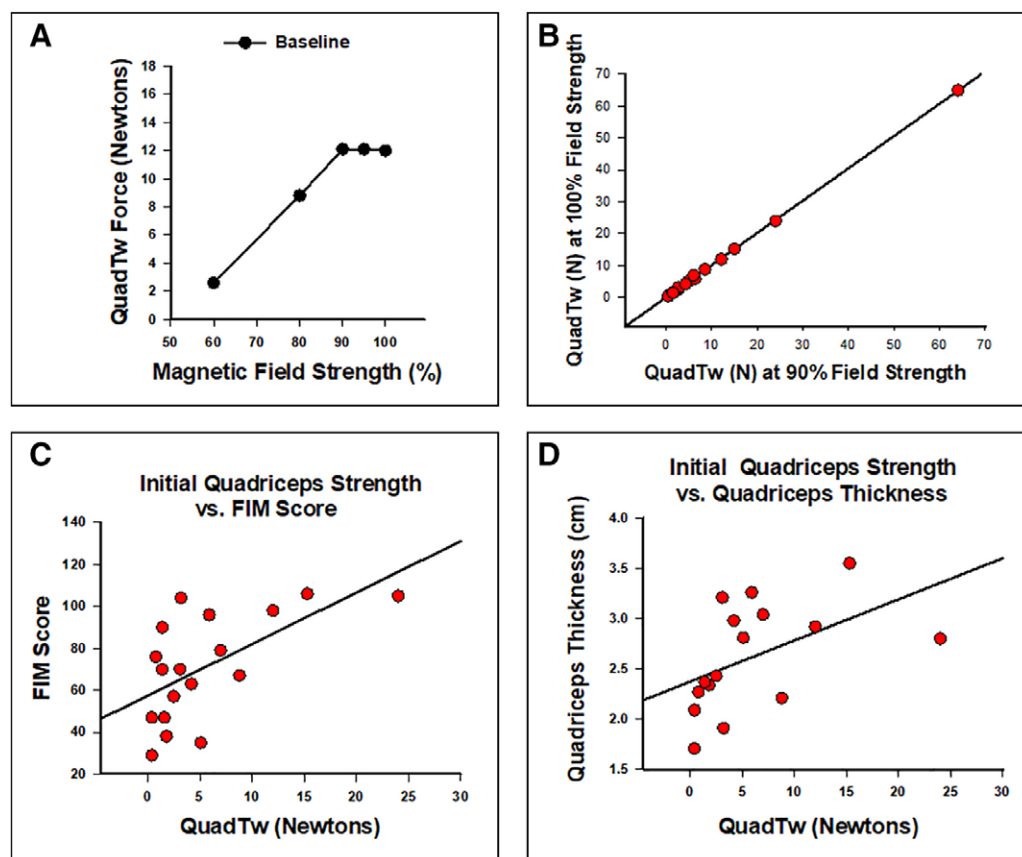


Figure 1. Relationship of baseline quadriceps strength to other variables. **A**, The baseline magnetic field strength–quadriceps twitch (QuadTw) force curve for a representative patient. As shown, force plateaus for magnetic field strengths between 90% and 100%, indicating that stimulation was supramaximal at a field strength of 100%. **B**, Comparison of force generation at field strengths of 100% (x-axis) and 90% (y-axis) for the initial quadriceps force (QuadTw) for all 19 patients who completed the study. These data indicate that QuadTw was supramaximal at 100% magnetic field strengths in all patients. Baseline QuadTw was linearly correlated with Functional Independence Measurement (FIM) scores (**C**, $p = 0.016$) and with quadriceps thickness (**D**, $p < 0.001$). For presentation purposes, (**C**) and (**D**) represent data for 18 subjects; one outlier was excluded from these graphs. This patient had a QuadTw strength of 65 Newtons, quadriceps thickness of 5.0 cm, and a FIM score of 110.

Fig. 2A). Total duration of PT varied substantially among subjects; importantly, longer durations of PT did not evoke larger increases in QuadTw ($p = 0.625$; **Fig. 2B**).

There was considerable variation in exercises prescribed for individual patients. On average, the most training time was spent performing resistive exercises and exercise machine training (SCIFIT), with lower proportions of training spent on other exercises (**Fig. 3A**). Multiple linear regression of the types of exercise provided did not reveal an overall statistically significant relationship to changes in QuadTw. Furthermore, regression of the duration of individual forms of exercise to strength changes also did not identify any specific form associated with an increase in strength (**Fig. 3, B and C**).

Most patients, on study entry, had extremely low QuadTw. We therefore examined the relationship between the PT provided to these patients prior to study entry and the initial

QuadTw. There was a poor correlation between initial QuadTw and the total number of prior PT sessions (initial QuadTw = $5.056 + [0.290 \times \text{Prior PT Sessions}]$; $r = 0.299$; $p = 0.213$). In addition, the total prior duration of PT received by patients with profound quadriceps muscle weakness at the time of study enrollment (i.e., QuadTw < 6 N) was substantial, averaging 298 ± 103 minutes.

Estimates Versus QuadTw Measurements

Physical therapists significantly overestimated initial QuadTw in 18 of 19 patients, estimating initial QuadTw to be a median value of 18 (25–75% CI of 15–30 N) while measured baseline median QuadTw was only 3.2 (25–75% CI of 1.4–8.8 N) ($p = 0.013$ for the comparison; **Supplemental Fig. 1A**, Supplemental Digital Content 4, <http://links.lww.com/CCM/F723> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]). Therapists also significantly overestimated improvements in QuadTw (**Supplemental Fig. 1B**, Supplemental Digital Content 4, <http://links.lww.com/CCM/F723> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]) after 2 weeks of PT. Specifically, physical therapists thought QuadTw increased in response to PT by a median of 1.8 N (25–75% CI of -0.01 N) while measured QuadTw changed by a median of -0.01 N (25–75% CI of -1.0 and 0.1 N) ($p < 0.001$).

Electromyogram Recordings During Physical Therapy

In the subgroup who had electromyogram recordings during PT sessions ($n = 9$), eight had high levels of leg muscle electromyogram activation during the first exercise of a training session, but substantially less muscle activation during subsequent exercises (**Fig. 4A**, representative electromyogram tracings for an individual patient). The QNIEMG significantly decreased during training sessions, falling from a median of 30.3 (25–75% CI of 16.7–46.1) for the initial exercise to 18.1 (25–75% CI of 2.6–24.4) for the final exercise ($p = 0.039$) (**Fig. 4B**). There was also substantial subject variation as to which specific exercise elicited high electromyogram responses (**Fig. 5**, representative tracings from three subjects). These data confirm that many patients spent considerable time during sessions performing exercises which elicited little muscle activation.

Respiratory Parameters and Physical Therapy

While recent studies suggest PT may improve lung and respiratory muscle function (20, 21), we found no correlation between PT duration or changes in Pi_{max} , an index of respiratory muscle strength (**Supplemental Fig. 2A**, Supplemental Digital Content 5, <http://links.lww.com/CCM/F724> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]) or the RSBI, an index of global respiratory system function (**Supplemental Fig. 2B**, Supplemental Digital Content 5, <http://links.lww.com/CCM/F724> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]).

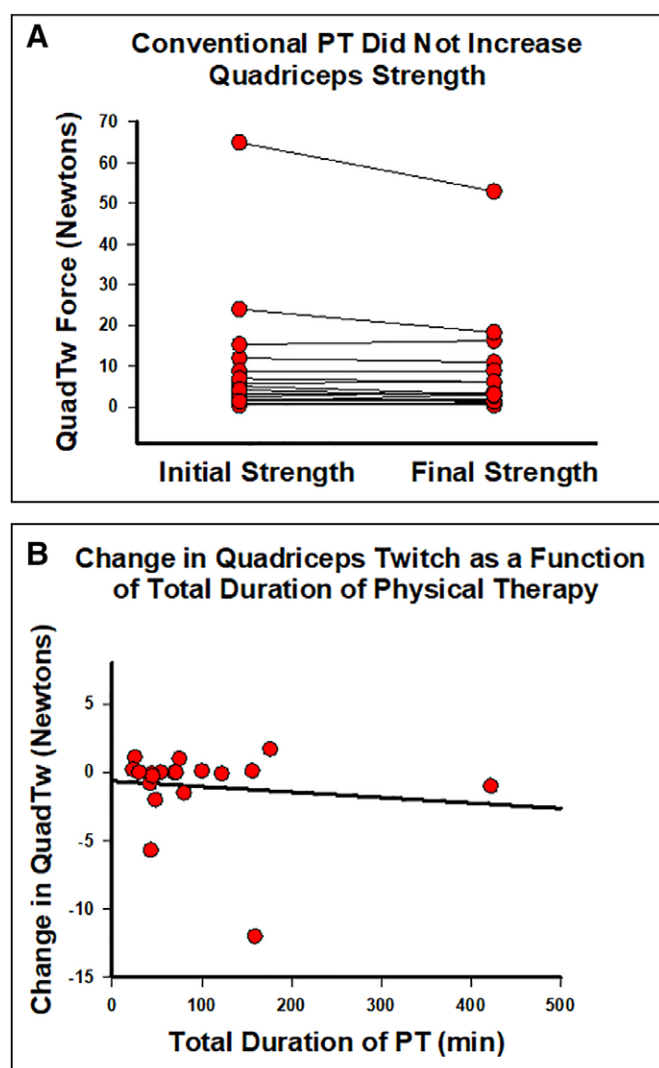


Figure 2. Changes in quadriceps strength in response to physical therapy. Quadriceps twitch (QuadTw) (**A**), an index of quadriceps muscle strength, did not significantly change in response to 2 wk of physical therapy (PT). Specifically, the net change between initial and final QuadTw values was -1.02 ± 0.71 N ($p = 0.819$). Patients received variable durations of PT. **B**, Longer durations of PT were not associated with larger increases in QuadTw ($n = 19$).

Physical Therapy Duration and Intensity

We also evaluated the relationship between initial QuadTw and the duration of PT patients received during the study. There was no consistent relationship between the duration of PT prescribed over 2 weeks and the initial QuadTw (PT duration = $82.734 + [1.294 \times \text{initial QuadTw}]$; $r = 0.210$; $p = 0.389$), with many weak patients receiving very short durations of PT (Supplemental Fig. 3A, Supplemental Digital Content 6, <http://links.lww.com/CCM/F725> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]). When we assessed the intensity of PT provided, using the total QNIEMG scores achieved

during PT sessions after study entry, and the initial QuadTw (Supplemental Fig. 3B, Supplemental Digital Content 6, <http://links.lww.com/CCM/F725> [legend, Supplemental Digital Content 1, <http://links.lww.com/CCM/F720>]), we found that stronger patients received higher intensities of PT (QNIEMG = $77.025 + [4.896 \text{ initial QuadTw}]$; $r = 0.937$; $p < 0.001$).

DISCUSSION

This is the first study to employ a novel technique, QuadTw, to assess changes in quadriceps strength in MV patients receiving PT. This technique (QuadTw force in response to magnetic

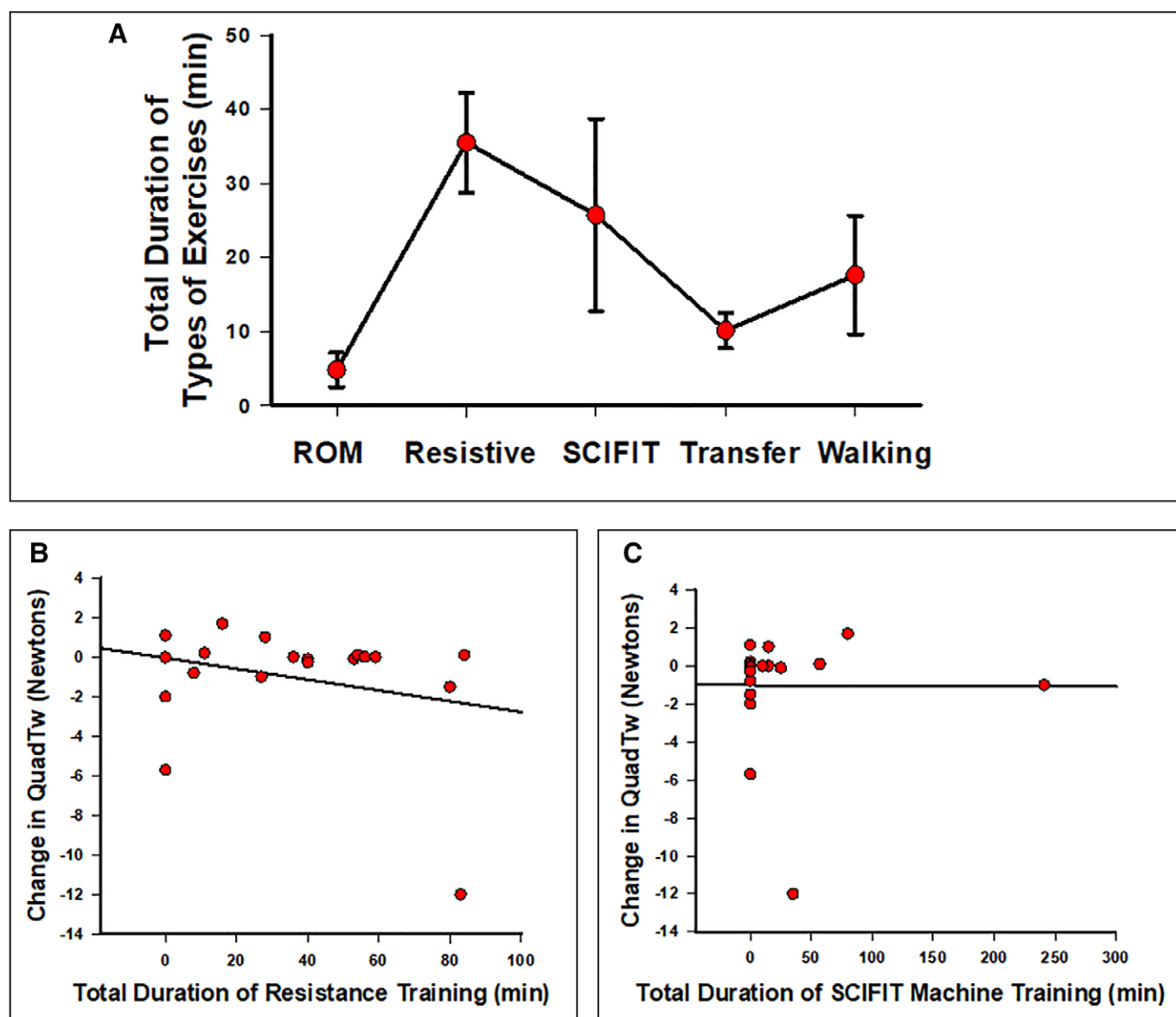


Figure 3. Patients ($n = 19$) were prescribed various combinations of different types of physical therapy (range of motion [ROM], resistive exercise, exercise using a SCIFIT exercise machine, transfer to sitting on the side of bed and standing, and walking with assistance) by the facility staff physical therapists. **A**, The average time (in min/patient) that each patient spent over 2 wk performing these various forms of exercise. To determine if any specific form of exercise was associated with improvements in quadriceps twitch (QuadTw), we correlated the time spent performing each form of exercise against the change in QuadTw over 2 wk. No individual form of exercise, however, was associated with a trend toward improvements in QuadTw. Regressions of QuadTw changes over time for the two types of exercise used to train patients (resistance training [**B**] and SCIFIT machine training [**C**]) are shown.

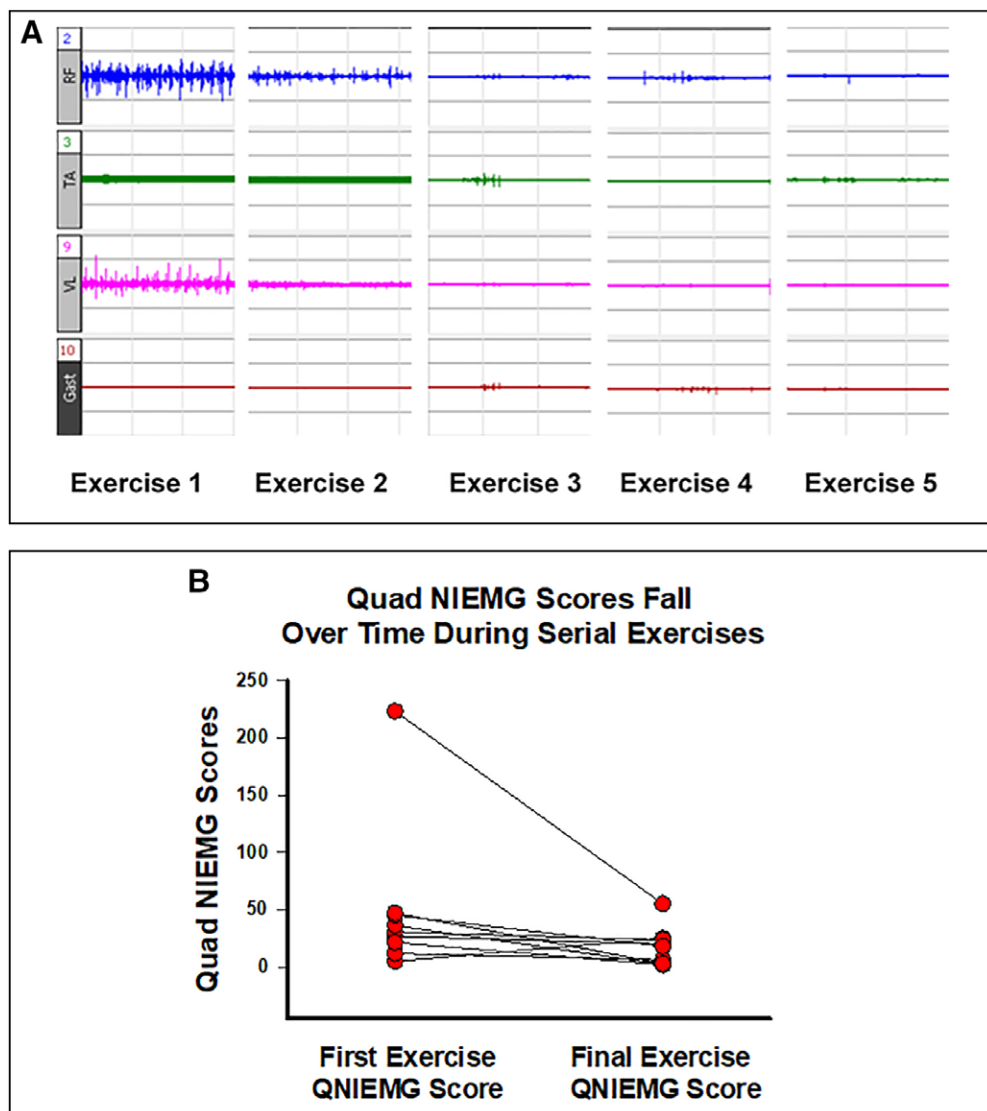


Figure 4. Quadriceps electromyogram tracings during exercise over time. **A**, Electromyogram (EMG) tracings from consecutive exercises in a training session for a representative patient. Recordings, from *top* to *bottom*, are from the rectus femoris (RF), tibialis anterior (TA), vastus lateralis (VL), and gastrocnemius (Gast) muscles. As demonstrated, this patient had substantial activation of leg muscles in the first exercise, but EMG activity levels fell progressively with latter exercises. In the subgroup of patients who underwent recordings of EMG activities ($n = 9$), this same pattern of reductions in EMG activation between the first and latter exercises occurred in most patients. **B**, The average EMG activity intensity (as quantified using Quadriceps Normalized Integrated EMG [QNIEMG] scores) decreased significantly between the initial exercise in the training session and the final exercise in the session ($p = 0.039$ for initial to final QNIEMG scores).

stimulation of the femoral nerve) provides a nonvolitional, purely objective index of quadriceps strength, allowing a precise determination of the effects of different exercises and durations of PT on leg muscle function in MV patients (12). In addition, this is also the first study to use electromyogram recordings to assess quadriceps muscle activation during PT training sessions in MV patients.

PT is standard care for rehabilitating MV patients, with the goal to improve patient outcomes (4, 5). Importantly, many questions remain regarding PT in these patients. Specifically, it is not entirely clear if some exercises are better than others or what intensities, durations, and frequencies of individual exercises are best (22). Importantly, all previous studies have

used volitional, highly subjective measurements to assess strength responses to PT in MV patients (7, 10, 23).

Previous studies examining the effect of PT on outcomes in MV patients have also suggested that aggressive PT may shorten the duration of MV (24, 25). The mechanism of this effect, however, is unclear. In theory, systemic exercise could improve lung function or respiratory muscle pump function. Alternatively, the initiation of aggressive PT could provide practitioners a strong incentive to markedly reduce sedation, facilitating weaning from MV, and independent of any specific effect of PT on respiratory function.

Surprisingly, we found that 2 weeks of conventional PT did not improve QuadTw in MV patients. Since the duration of PT varied for individual subjects, we also considered the possibility that longer durations of PT might produce greater increases in strength. Unfortunately, longer durations of PT were no better than shorter durations. Since individual patients were prescribed different combinations of exercises during PT sessions, we also analyzed the impact of different forms of exercise on strength changes and found no single form of training that was associated with increases in quadriceps strength.

One might suggest that 2 weeks of PT may be too short a time to elicit a significant increase in quadriceps muscle strength and that much longer durations of therapy may be needed to produce an increase in force generation. Most subjects had been at Rockcastle Medical Center for significant time periods before enrollment and had received substantial durations of PT before study inclusion. Logically, patients receiving substantial PT for protracted periods prior to study inclusion might have been expected to have higher initial quadriceps strength at the time of study inclusion; however, there was a poor correlation between the duration of PT prior to study inclusion and initial QuadTw. These data suggest that PT prior to study entry was also ineffective in treating quadriceps weakness.

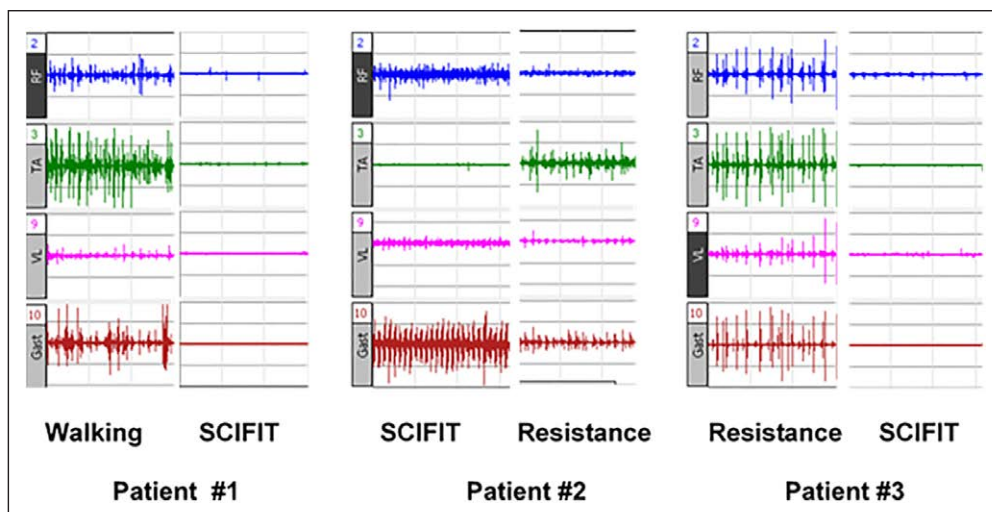


Figure 5. We observed significant exercise-to-exercise variation in electromyogram (EMG) activities for different forms of exercise for most subjects. As shown, patient number 1 had high levels of EMG activation during walking but virtually no activation while using the SCIFIT exercise machine. On the other hand, patient number 2 had high levels of muscle activation using the SCIFIT machine but less activation during resistance training and patient number 3 had high levels of activation during resistance training but low levels of activation when using the SCIFIT machine. Gast = gastrocnemius, RF = rectus femoris, TA = tibialis anterior, VL = vastus lateralis.

It could be argued that the technique we employed to assess quadriceps strength may be flawed, that is, (QuadTw), being relatively insensitive to improvements in muscle function. Our QuadTw technique, however, was patterned after the use of magnetically stimulated twitches to assess diaphragm function, that is, determination of the transdiaphragmatic pressure generation in response to bilateral magnetic stimulation of the phrenic nerves (21, 26–28). While experience with the QuadTw technique is less than that for the diaphragm in MV patients, the data from the present study demonstrate that baseline QuadTw measurements were strongly correlated with the FIM score, a patient centered index of the ability of subjects to perform common tasks of daily living (16). It should also be noted that QuadTw has been used in multiple previous studies of outpatients with chronic pulmonary diseases as a valid index of leg muscle function (29–33).

Another question is whether or not assessment of quadriceps thickness, the technique used in the present study, is the best muscle size parameter to use in studies such as this. Since we began this work, some reports suggest that measurement of muscle cross-sectional area may be preferable to thickness indices (34). In the case of the current study, however, baseline quadriceps thickness did, in fact, correlate well with baseline quadriceps force. Since our nonvolitional, quantitative index of quadriceps strength (QuadTw) did not increase with PT, there is no reason to believe that alternative techniques to assess muscle size would have altered the conclusions of the study.

A more important question is why patients failed to respond better to PT. We suggest that there are at least three logical explanations for this failure: 1) patient characteristics resulted in anabolic resistance (i.e., poor nutrition, concurrent infection, age, chronic comorbidities, and muscle inexcitability due to neurotransmission defects or muscle necrosis); 2) delivery

of insufficient PT; and/or 3) a need for concomitant administration of anabolic drugs to optimize muscle regrowth. As indicated in the Methods, the cohort of patients studied had completed the initial phase of their illnesses, had recovered from infections, were not sedated, were not febrile, were ingesting adequate food, were able to give consent, were able to cooperate with PT, and were not receiving IV medications. As a result, there was no reason to believe these patients had poor nutritional intake or high levels of inflammation based on their clinical presentation at the time of study inclusion. There is a strong possibility, however, that their chronic diseases and age may

have been factors limiting their ability to improve strength in response to what most would have thought were adequate levels of exercise. In addition, some critically ill patients develop nerve damage and/or muscle necrosis with a subsequent reduction in the ability to activate muscles due to overt sarcolemmal damage (35, 36).

Another possibility, however, is that patients simply did not perform strenuous enough exercise, even though higher levels were physiologically possible. Our electromyogram recordings indicate that patients failed to sustain high levels of muscle activation during exercise, with most patients achieving high levels of leg muscle activation with the first exercise and substantially lower levels with each subsequent exercise. We also found that most patients had a specific exercise where they achieved relatively high levels of leg electromyogram activation, but achieved mediocre levels of electromyogram activation with other exercises. Since therapists were unaware as to when patient electromyogram intensity declined or which exercises elicited high levels of muscle activation, exercise efficiency was poor, with large portions of training sessions wasted because patients were performing exercises that elicited little muscle activation. These problems were exacerbated by the fact that physical therapists overestimated the effects of PT on muscle strength in individual patients. As a result, physical therapists thought patients were improving and had little reason to worry that muscle activation may be suboptimal.

There are several potential criticisms of the current work. First, this study was conducted at a single facility and one might argue that, because of this issue, our findings cannot be extrapolated globally. We believe future studies examining the issues raised by the current work will be required, but we should point out that the current findings are critically important for future work. Without the information in the current

report, it would be almost impossible to design additional studies examining these issues.

One might also argue that the number of patients enrolled in the current study is small and that a beneficial effect might have been observed had the number of studies been increased. In other words, it could be argued that we may have a type 2 error in our data examining strength. Power analysis, using the standard deviations and differences in means from the present data indicates, however, that a larger study would require 1,541 patients to detect a potential change in QuadTw strength in response to PT of 1 Newton. While such a study may detect a statistically significant change, such a change would not be clinically significant.

Finally, as this was an observational study and no intervention was used, there is no control group. It could be argued that the appropriate control group should consist of MV patients who do not receive any PT for 2 weeks. Inclusion of such a control group would be unlikely to obtain IRB approval, however, as it would be unethical.

CONCLUSIONS

The present findings have important implications for the “PT prescription” applied to MV patients. First, our data suggest that simply increasing PT duration may not improve responses, since patient electromyogram activation declines as an individual training session continues. A better approach may be to provide more frequent and shorter PT sessions. Second, it may be important for therapists to focus PT on specific forms of exercise that elicit the highest levels of muscle activation. Arguably, this would best be accomplished by determining electromyogram activation patterns during specific exercises and tailoring therapy to these patterns (37–39).

We suggest, however, that the present study was a necessary first step in evaluating the PT prescription. We have identified and defined the limitations to conventional PT more precisely than past work and also have demonstrated the utility of employing quantitative techniques (i.e., electromyogram recordings, magnetic twitch monitoring of muscle function) to measure responses to PT/adjunctive therapies. Use of such techniques, moreover, should prove to be helpful in individualizing exercise prescriptions as well as assessing responses to physical training in additional studies. Future studies will be needed to test these theories and determine the durations and types of exercises required to attain optimal improvements in muscle function for MV patients.

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