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A standard technique with potential diagnostic value for estimating the quadriceps muscle strength of critically ill patients

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Abstract. – OBJECTIVE: Intensive care unit-acquired weakness (ICUAW) is common, and so far, there is no digital technology with a standard procedure to estimate the muscle strength of these patients. Quadriceps maximal isometric voluntary contraction (QMVC) is a precise and reliable procedure to detect quadriceps muscle strength. Therefore, this research aimed to explore whether QMVC measurements can be used in critically ill patients at the bedside as a potential diagnostic method.

PATIENTS AND METHODS: Tailor-made computerized equipment was designed to measure the QMVC of critically ill patients at the bedside, following a standard procedure. A total of 22 critically ill patients and 22 age- and sex-matched healthy subjects were divided into group 1 and group 2, respectively. SPASS 21.0 (IBM, Armonk, NY, USA) software was used to analyze the data.

RESULTS: All subjects showed good endurance with the QMVC measurements and there were no side effects among these subjects. There was a significant decline in QMVC between group 1 and group 2 (p=0.000). QMVC was correlated closely with the APACHE II Score in group 1 (Pearson correlation, r=–0.427, p=0.047). Among the 10 patients with a Medical Research Council sum score (MRC SS) less than 60 in group 1, it was also correlated closely with the MRC SS (Pearson correlation, r=0.837, p=0.003).

CONCLUSIONS: This study describes a standard technique for quantifying quadriceps muscle strength that is feasible for use with critical patients. QMVC can accurately detect the decline of quadriceps muscle strength of critical patients, and it may also decline with the severity of the disease. In the future, this technique might be a potential diagnostic tool for ICUAW.

Key Words:

Intensive care unit, Quadriceps muscle, Critical illness, Muscle weakness.

Introduction

Mortality following critical illness has been significantly reduced in the past few decades and an increasing number of patients are surviving critical illnesses due to the efforts of the medical staff. Unfortunately, survivors often suffer from many complications after recovery[1-3]. Intensive care unit-acquired weakness (ICUAW) is a common complication following critical illness, and it typically presents as muscle atrophy and weakness in a symmetrical pattern[1,3]. ICUAW is an important clinical consequence and a prognostic indicator of critical illness, and it dramatically affects the recovery of the patients. ICUAW can lead to prolonged mechanical ventilation, increased length of stay in the ICU and hospital, limb muscle dysfunction and even disabilities[4-7].

How to estimate muscle function in a timely manner with an accurate and standard technology is necessary and pressing. Generally, ICU physicians diagnose this condition with the Medical Research Council sum score (MRC-SS), which was originally developed to evaluate patients with Guillain-Barre syndrome (GBSB)[1,7]. To some extent, this manual muscle testing is limited because it cannot give a precise digital result, and it cannot measure a strength grade more than 5 for each muscle or 60 for 12 muscles[8-11]. Electrophysiological studies and muscle biopsies may accurately indicate impairment of nerve and muscle; nevertheless, they are limited due to their complexity, costliness and invasiveness[12,13].

Recently, some hand-held dynamometers used in sports activities were studied to determine voluntary contraction of muscles, but there is no standard operating procedure for these tools[2,14]. In fact, among patients with ICUAW, quadriceps muscle strength and quadriceps muscle mass decrease more seriously than other limb mus-

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cle groups[5,15-17]. Therefore, is there some precise digital technology with a standard procedure to detect the quadriceps muscle strength of critically ill patients? Quadriceps maximal isometric voluntary contraction (QMVC) has been widely used to evaluate limb muscle dysfunction in chronic obstructive pulmonary disease, and it is also used as a marker of morbidity and mortality in congestive cardiac failure[10,18].

There is an official standard operating procedure for this technique, and furthermore, the methodology can be implemented in clinical practice. Historically, this measurement is implemented in a special laboratory[10,19,20]. Thus, a particularly interesting question is whether it can be implemented at the bedside in an intensive care unit (ICU) for estimating the muscle strength of critically ill patients,

Therefore, this clinical research aimed to answer three questions below: First, could QMVC measurement with a computerized test system be performed at the bedside in an ICU? Second, could QMVC detect the decline of quadriceps muscle strength of critically ill patients? Third, is there a correlation between QMVC and the severity of disease?

Patients and Methods

Subjects and Study Design

This study was conducted in the Intensive Care Unit (ICU) of Fuling Central Hospital of Chongqing. From July to December 2019, there were 22 critically ill patients who had been mechanically ventilated for more than 48 h (Group 1), and 22 age- and sex-matched healthy persons (Group 2). The following patients were excluded: primary neuromuscular disorders, severe trauma, coma, cardiac or cerebral vascular accident, unstable or unwilling to be measured. Two ICU therapists who had worked for over ten years were trained until they were skilled in QMVC measurements. The APACHE II Score was obtained on the first day that a critically ill patient was admitted to the ICU[21]. QMVC measurements were obtained from critically ill patients when they were released from the ICU to the general ward. This investigation was approved by the Research Ethics Committee of Fuling Central Hospital, and written informed consent was obtained from the subjects or their authorized representatives.

Designing the Measuring Apparatus

A dual-purpose chair for sitting and lying was designed, and a special fixing rack was welded under the chair. On the rack, there is a pulley that could be fixed on an upright post at different heights. A force transducer (HBM, Darmstadt, Germany) with a fastener connected with an inelastic strap was fixed on the headpiece of the rack. A digital signal converter (OMG, USA) was fixed between the transducer and a laptop. To make the device easier to move, a mobile battery (SM-398, AUNQS, China) was used to stimulate the transducer. The structural design of the equipment is shown briefly in Figure 1.

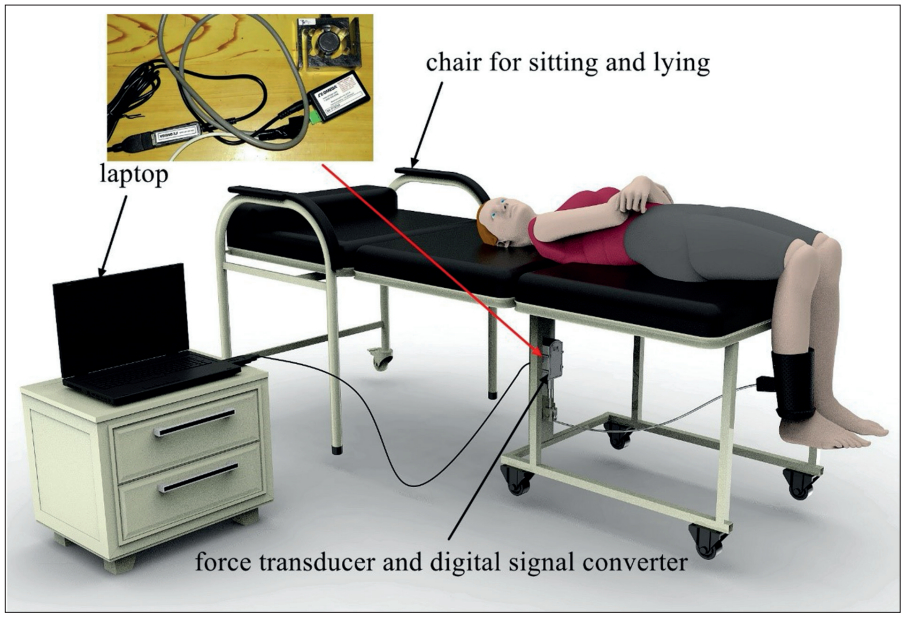

Figure 1. Measuring apparatus for QMVC (quadriceps maximal isometric voluntary contraction) measurement and the posture of the patient.

QMVC Measurement Procedure

The quadriceps maximal isometric voluntary contraction technique (QMVC) following a standardized technique was used to assess quadriceps muscle strength (Figure 1). The subject lay in a supine posture over the purpose-built chair with the knee flexed at 90° at the end of the chair. The ankle of the dominant leg was fixed in a nonelectric strap that was linked to the force transducer. The real-time force curve was displayed and recorded on a computer running Omega Data Logger Software Version 4.2.5.0 (OMG, USA). The QMVC force was reported in newton. During the measurement, the subject needs to be vigorously encouraged to stretch their calf forward continuously and repeatedly. At least three sustained reproducible maneuvers of QMVC between 4 and 6 s duration were performed by the subjects. When the force curve reached a plateau, the correspondent value was regarded as QMVC (Figure 2). The time of the curve plateau should be more than 1 full second.

APACHE II Score and MRC SS

The APACHE II score is a mortality prediction tool that has been commonly used for many years in critically ill patients. This score is closely related to the severity of the disease[21]. The Medical Research Council sum score (MRC-SS) is a method of manual muscle testing that was developed for patients with Guillain-Barré syndrome (GBSB). In recent years, it has been used to grade six muscle groups bilaterally in critically ill patients, and a combined score of less than 48 is used a cutoff for the diagnosis of ICUAW[1,4]. Each muscle strength is graded from 0 to 5, and the full mark of this score system is 60, so it cannot detect strength greater than 60.

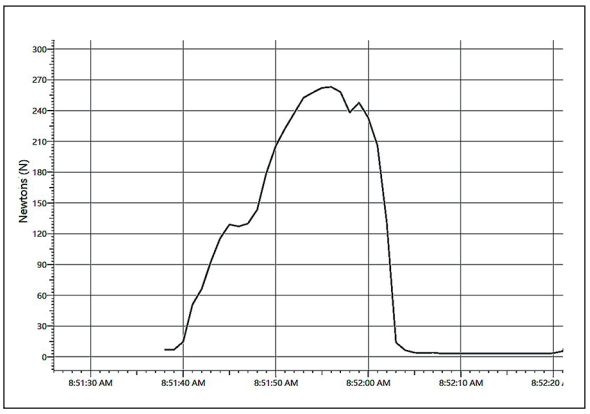

Figure 2. Real-time strength curve of QMVC (quadriceps maximal isometric voluntary contraction). The horizontal ordinate is the real-time measurement, and the vertical ordinate is QMVC. N = newton.

Statistical Analysis

The data are shown as means ± SD. Variables between groups were compared with t-tests. Possible correlations between the QMVC and APACHE-II Score were evaluated with Pearson correlations. A p-value of <0.05 was regarded as significant. SPASS 21.0 (IBM, Armonk, NY, USA) statistical software was used for all statistical work.

Results

Subject Characteristics

The characteristics of all of the subjects are listed in Table I. There were no significant differences in the baseline demographics of subjects between group 1 and group 2.

QMVC, APACHE II Score and MRC SS

All subjects showed good endurance during the QMVC measurement, and there were no side effects found among these subjects. The real-time strength is displayed in a strength-time curve, and all of the collected curves were good enough to meet the measurement needs (Figure 2). QMVC declined significantly in group 1 compared with that in group 2 (Table II, p=0.000). QMVC of group 1 was closely correlated with APACHE II Score (Pearson correlation, r=−0.427, p=0.047) (Table III). Among 10 patients with an MRC sum score (MRC SS) less than 60, the QMVC was also closely correlated with the MRC SS (Pearson correlation, r=0.837, p=0.003) (Table IV).

Discussion

In this study, QMVC has been transferred from the respiratory mechanics laboratory to the bedside of critical patients for the first time; moreover, the computerized test system has been shown to be practical and applicable in the ICU. During the process of measurement, the critically ill patients were transferred on the test chair by the carers, and the procedure was well tolerated by all critically ill patients. One of the key components in the procedure is that the critically ill patients need to try their best to stretch their shanks and hold

Table I. Subject demographics.

	Group 1	Group 2
Age, year	58.23 ± 17.50	58.36 ± 16.83
Sex, male	11	11
Sex, female	11	11
BMI, kg/m²	23.5 ± 2.6	24.5 ± 3.4
Barthel Index	100	100
Admitting conditions		
Severe sepsis	8	
COPD exacerbation	4	
Poisoning	5	
Trauma	1	
Surgery	4	
Mechanical ventilation, hr	74.27 ± 16.69	
APACHE Score	18.73 ± 5.72	

Values are expressed as means ±SD. BMI, body mass index; Barthel Index: indexes about daily living that one can perform (Barthel Index of group 1 is data before this critical ill); COPD, chronic obstructive pulmonary disease; APACHEII Score: a score to estimate critical ill patients and their prognosis. Group 1 is that critical ill patients, Group 2 is control group. There is no statistical difference between group 1 and group2 in age, sex, BMI, and Barthel Index ($p < 0.05$).

the hardest position unchanged for more than one second when the force reaches the maximum. Although this sounds challenging, all patients with different diseases and ages successfully fulfilled this task the first time in this study. There were no side effects found in the measuring process among all subjects, and it does not obstruct the continuous monitoring of patients.

Loss of skeletal muscle strength is a typical symptom in critical patients, especially in IC-

Table II. QMVC of subjects.

	Group 1	Group 2
Subject 1	177.1	345.9
Subject 2	226.1	189.6
Subject 3	150.2	328.8
Subject 4	158.1	228.9
Subject 5	29.1	273.3
Subject 6	66.5	284.9
Subject 7	87.8	260.0
Subject 8	123.9	252.5
Subject 9	59.1	305.7
Subject 10	172.6	282.5
Subject 11	155.8	254.3
Subject 12	196.1	234.4
Subject 13	30.1	270.5
Subject 14	60.2	365.8
Subject 15	58.3	286.2
Subject 16	98.9	301.1
Subject 17	223.5	447.7
Subject 18	340.5	344.5
Subject 19	277.5	323.7
Subject 20	137.3	390.3
Subject 21	171.5	393.6
Subject 22	219.6	265.9
Means ±SD	146.36 ± 81.72	301.37 ± 61.53

QMVC is quadriceps maximal isometric voluntary contraction and N is newton. Group 1 is critical ill patients. Group 2 is control group. QMVC of group 1 significantly decrease than that of group 2 ($p = 0.000$).

Table III. QMVC and APACHE-II Score of group 1.

	QMVC (N)	APACHE-II score
Subject 1	177.1	14
Subject 2	226.1	27
Subject 3	150.2	21
Subject 4	158.1	9
Subject 5	29.1	20
Subject 6	66.5	26
Subject 7	87.8	20
Subject 8	123.9	21
Subject 9	59.1	24
Subject 10	172.6	21
Subject 11	155.8	11
Subject 12	196.1	26
Subject 13	30.1	25
Subject 14	60.2	18
Subject 15	58.3	26
Subject 16	98.9	14
Subject 17	223.5	18
Subject 18	340.5	13
Subject 19	277.5	14
Subject 20	137.3	17
Subject 21	171.5	19
Subject 22	219.6	8

QMVC is quadriceps maximal isometric voluntary contraction and N is newton. Group 1 is all the critical ill patients. Pearson correlations between QMVC and APACHE-II Score of these patients is significant ($p = 0.047$).

Table IV. QMVC and MRC SS.

	QMVC (N)	MRC SS
Subject 1	177.1	52
Subject 2	29.2	40
Subject 3	66.5	42
Subject 4	59.1	48
Subject 5	172.6	56
Subject 6	155.8	52
Subject 7	30.1	36
Subject 8	60.2	36
Subject 9	58.3	42
Subject 10	98.9	54

Among 10 patients with MRC SS < 60 in Group 1, QMVC is closely correlated with MRC SS, person correlations, $p = 0.003$.

UAW patients. In the study, the QMVC of critically ill patients declined significantly among critical patients, indicating it could detect the decline of skeletal muscle strength in critically ill patients. In fact, many researchers in the COPD field have suggested that QMVC can detect a slight decline of quadriceps strength among patients with COPD[10]. The close relationship between QMVC and the APACHE-II Score shows that the QMVC could decline along with the severity of diseases, in other words, it could reflect the severity of disease. Another interesting finding is that QMVC is closely correlated with MRC SS among patients with MRC SS <60. Therefore, considering the diagnostic value of MRC SS in ICUAW, QMVC could be a potential tool for diagnosing ICUAW. Because it uses a force transducer, it could be more precise than manual measurements and it could well meet the demands of precision medicine.

From pathological study, we know the typical pathologic manifestation in ICUAW is a shift in fiber type distribution, in other words, type II fibers atrophy rapidly[1,18]. Type I fibers are involved in slow-twitch movements but type II fibers are involved in fast-twitch movements. ICUAW impairs the lower extremities more seriously than the upper limbs, particularly the quadriceps muscle, because type II fibers account for around 48% of the total quadriceps muscle. According to pathologic and clinical findings, quadriceps muscle strength could be a potential representative marker instead of total limb muscle groups.

Our research is, as far as we know, the first time that a QMVC test has been studied in the domain of ICUAW, and this technique facilitates moving the measurement from the laboratory to the bedside in the ICU. This procedure could be used as a method with greater accuracy for diagnosing ICUAW. However, there are also some limitations to our study. In this study, muscle mass and muscle endurance have not been explored, and they might be closely related to muscle function. Therefore, more research needs to be done to obtain medical evidence about this method.

Conclusions

In summary, this study describes a standard, straightforward technique for quantifying quadriceps muscle strength, which has been transferred from the respiratory mechanics laboratory to the bedside of critical patients for the first time. QMVC could be used to estimate the quadriceps muscle strength of critically ill patients; moreover, it could be negatively correlated with the severity of disease. This technique could be a potential diagnostic tool for ICUAW, though its practical meanings and future prospects need to be confirmed with additional research.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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