Handgrip Force and Maximum Inspiratory and Expiratory Pressures in Critically Ill Patients With a Tracheostomy

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Background The association between peripheral striated muscle strength and respiratory muscle strength has been confirmed in a number of disorders. However, this association is unknown in intensive care unit patients with tracheostomies.

Objective To examine correlations between handgrip force, maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP) in intensive care unit patients with tracheostomies.

Methods Twenty patients (7 women, 13 men) with tracheostomies, in the intensive care unit longer than 11 days, in stable condition, with functional limbs, and with Glasgow Coma Scale scores of 15 were recruited. Both MIP and MEP were measured with a membrane manometer; handgrip force was measured with a hydraulic hand dynamometer.

Results Handgrip force was significantly correlated with MIP ($r=0.45$, $P=.04$) and MEP ($r=0.78$, $P=.001$). Handgrip force was significantly predicted by MIP and MEP when the effect of sex was controlled for ($P<.05$). However, when MIP and MEP were included as predictors in a regression model, MEP was the only significant predictor ($R=0.80$, $R^2=0.63$, adjusted $R^2=0.57$).

Conclusions Strength of the hand flexors and strength of the expiratory muscles (abdominal) were significantly correlated in intensive care unit patients. Handgrip strength appears to be an easy, fast way to evaluate expiratory muscle strength by using a simple handhold command without special equipment. A strong handhold may also correspond to strong expiratory muscles.

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Maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) are functional magnitudes used to evaluate the force of the respiratory muscles (diaphragm, abdominal wall muscles, and intercostal muscles).[1] Both parameters are used to evaluate potential damage to these muscles, which can occur in intensive care unit (ICU)–acquired weakness (ICU-AW),[2,3] a neuromuscular disorder that affects approximately 30% to 50% of ICU patients because of prolonged ICU stay and is associated with significant morbidity and mortality. Recording MIP and MEP in the hospital is easy and noninvasive, so these parameters are often used in clinical practice to evaluate the functional ability of the respiratory system.[4,5]

Respiratory muscles are skeletal muscles that work together in the rhythm of contraction and relaxation during breathing. Respiratory muscles have a dynamic relationship with peripheral striated muscles[5,6]; strengthening 1 muscle group has a positive effect on the others.[7] The relationship between these muscle groups has been confirmed in a number of disorders, including chronic obstructive pulmonary disease,[8,9] cardiac failure,[10] lateral amyotrophic sclerosis,[5] and critical illness myoneuropathy.[11]

For patients in the ICU, tracheostomy ensures a secure airway and facilitates removal of secretions. However, most patients with tracheostomies (approximately 80%) experience prolonged intubation, which increases the risk of ICU muscle weakness. Therefore, measuring handgrip force (HGF), MIP, and MEP is important for continuous monitoring of critically ill patients.[12]

Handgrip force is a representative indicator of the force of the peripheral muscles. Measurement of HGF is a common, noninvasive method of estimating the functional status of critically ill patients.

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Handgrip force is reliable for evaluating outcomes (eg, survival prognosis) of patients with certain conditions.[13-16] Handgrip force can also indicate cardiorespiratory function in patients with conditions such as chronic obstructive pulmonary disease[13] and chronic cardiac failure.[14]

The relationship between HGF, MIP, and MEP has been studied in patients with fibromyalgia,[15] in elderly patients,[17] in patients with sarcopenia,[18] in patients with cardiac failure,[19] and as an indicator of frailty.[20] These studies have shown a remarkable correlation between the forces of peripheral and respiratory muscles. In patients with cardiac failure, decrease in respiratory muscle strength may be attributed to general myopathy, which is very common in this condition.[16]

Although the association between HGF and maximal respiratory pressures is well established, to our knowledge this association has never been investigated in critically ill patients in the ICU. Examination of this association in this patient population could allow respiratory muscle force (measured with MIP and MEP) to be calculated from HGF. The respiratory function of severely ill patients could also be empirically assessed with a simple measurement of maximum handhold force. This association could be used clinically to predict the HGF of patients with nonfunctional upper limbs, the MEP of patients with a tracheostomy (without cuff), and the MEP of patients with reduced ability to communicate or cooperate.

> Respiratory muscles have a dynamic relationship with peripheral striated muscles.

In a study by De Jonghe et al,[21] ICU-AW occurred in 24 of 95 patients (25.3%) who received mechanical ventilation for at least 7 days, survived to awaken, and could follow commands (ICU-AW was defined as a Medical Research Council score for manual muscle strength of less than 48, consistent with severe

Table 1
Characteristics of the sample (N=20)

Characteristic	Mean (SD); median (IQR)[a]
Age, y	68.1 (12.4); 73 (62.2-73.9)
Men, No. of patients	13
Weight, kg	76.4 (15.1); 72 (69.3-83.4)
Height, cm	168 (9); 167.5 (163-172.3)
Maximum inspiratory pressure, cm H_2O	35.6 (11.3); 35 (30.3-40.9)
Maximum expiratory pressure, cm H_2O	40.2 (10.5); 40 (35.2-45.1)
Handgrip force, kg	11.4 (7.4); 10 (7.9-14.9)
Body mass index[b]	27 (4.9); 26 (24.7-29.3)
Day of ICU hospitalization	19.6 (7.8); 19.5 (15.9-23.3)
SOFA score	3.6 (1.6); 3 (2.8-4.4)
Primary reason for ICU admission, No. of patients	
Coronary artery bypass graft	1
Cardiac valve replacement	1
Respiratory failure	9
Alcoholic hepatitis	1
Chronic obstructive pulmonary disease	1
Abdominal surgery	2
Sepsis/cirrhosis	1
Myocardial infarction/heart failure	3
Aortic aneurysm	1

Abbreviations: ICU, intensive care unit; IQR, interquartile range; SOFA, Sequential Organ Failure Assessment.
[a] Unless other units indicated in first column.
[b] Calculated as weight in kilograms divided by height in meters squared.

weakness and reflecting an inability to resist gravity). The most consistently implicated risk factors were those associated with severity of illness, including shock, sepsis, and degree of multiple organ failure.[21,22] The objective of our study was to examine (to our knowledge, for the first time) the correlations between HGF, MIP, and MEP in severely ill patients in the ICU.

Methods

This was a retrospective observational study conducted from May 2017 through January 2018 with a sample of 20 ICU patients. Data were collected from the patients' medical records.

We used linear regression analysis to predict HGF from MIP and MEP.

The study included patients more than 18 years of age who were hospitalized in the ICU for more than 11 days (ICU-AW occurs after 10 days of hospitalization[23,24]). Patients included were hemodynamically stable and were able to perform commands and breathing exercises (Glasgow Coma Scale score of 15). Patients included in the study also had a good level of communication, a level of consciousness sufficient to execute orders, and intact limbs. Patients were excluded if they had any neurological syndrome (central or peripheral), craniocerebral injury, or condition that could affect peripheral muscle strength or were taking any medication that could affect perception or muscle tone.

Measurements and Testing Procedures

The MIP and the MEP are valid indicators of the condition of the respiratory muscles. The most commonly used and reliable tool for recording MIP and MEP is the membrane manometer.[25] We assessed HGF with a handheld dynamometer (Baseline hydraulic dynamometer, Medline Industries).[26]

We collected the following data from patients' medical records: MIP, MEP, HGF, age, weight, height, Glasgow Coma Scale score,[27] creatinine level, receipt of inotropic medications, $Pa{O_2}$, platelet count, bilirubin level, oxygen supply (fraction of inspired oxygen), and day of and reason for hospitalization in the ICU. The Sequential Organ Failure Assessment (SOFA) was used to determine the severity of each patient's condition.

Statistical Analysis

Descriptive statistics are presented as means with SDs, medians with interquartile ranges, or percentages as appropriate. The Shapiro-Wilk test was used to determine whether the variables of interest followed a normal distribution. Correlations were examined with the Pearson correlation coefficient (r). A correlation coefficient of less than 0.20 indicates a very weak correlation; of 0.21 to 0.40, a weak correlation; of 0.41 to 0.60, a moderate correlation; of 0.61 to 0.80, a strong correlation; and of 0.81 to 1, a very strong correlation.[28,29] We used linear regression analysis to predict HGF from MIP and MEP. The regression analysis was performed in hierarchical order to control for the confounding influence of sex on HGF. We constructed 3 models. Model 1 used both MIP and MEP to predict HGF, model 2 used only MEP to predict HGF, and model 3 used only MIP to predict HGF. Sex was included in the first block of predictors for each of the 3 models. We used χ^2 tests of independence to compare the frequency of strong MEP with strong and weak HGF. The significance level was set at a P of .05. We used SPSS version 20.0 (IBM) for all data analyses.

Results

Participants' demographics and descriptive data regarding day of and primary reason for ICU hospitalization are presented in Table 1. Age, sex, body mass index (calculated as weight in kilograms divided by height in meters squared), height, and weight were not significantly correlated with MIP or MEP ($P > .05$). Handgrip force was not significantly correlated with SOFA score ($r = 0.04$, $P > .05$), ICU day ($r = -0.28$, $P > .05$), or body mass index ($r = -0.37$, $P > .05$). Maximum inspiratory pressure was not significantly correlated with SOFA score ($r = 0.01$, $P > .05$), ICU day ($r = 0.27$, $P > .05$), or body mass index ($r = 0.03$, $P > .05$). Maximum expiratory pressure was not significantly correlated with SOFA score ($r = -0.16$, $P > .05$) or ICU day ($r = -0.32$, $P > .05$) but was significantly correlated with body mass index ($r = -0.53$, $P = .02$). In all cases, a strong HGF (>10 kg) corresponded to a strong MEP (>37 cm H_2O) ($\chi^2_1 = 8.1$, $P = .008$).

Significant positive correlations emerged between HGF and MIP ($r = 0.45$, $P = .04$), between HGF and MEP ($r = 0.78$, $P = .001$), and between MIP and MEP ($r = 0.62$, $P = .004$) (see Figure).

The constructed model 1 ($R = 0.80$, $R^2 = 0.63$, adjusted $R^2 = 0.57$), model 2 ($R = 0.80$, $R^2 = 0.63$, adjusted $R^2 = 0.59$), and model 3 ($R = 0.47$, $R^2 = 0.28$, adjusted $R^2 = 0.13$) significantly fit to the data overall ($P < .05$). In model 1, MIP was not found to be a significant predictor of HGF ($P = .97$), potentially because of its high correlation with MEP ($r = 0.59$, $P = .006$). The models are presented in Table 2.

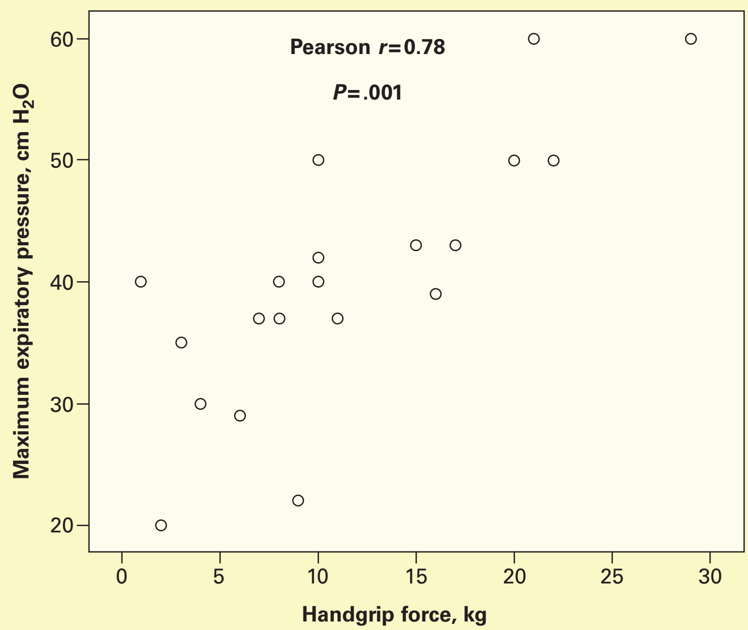

Figure Correlation of handgrip force with maximum expiratory pressure.

Table 2
Regression model for the prediction of handgrip force

Model	Predictors[a]	*r*	Partial *r*	*B*	SE	β	*P*
1	Constant	—	—	–12.92	5.37	—	.03
	Sex	–0.09	0.14	2.33	2.62	0.15	.39
	MEP	0.78	0.65	0.58	0.14	0.82	.001
	MIP	0.45	0.005	0.005	0.14	0.007	.97
2	Constant	—	—	–12.85	4.78	—	.02
	Sex	–0.09	0.14	2.30	2.34	0.15	.34
	MEP	0.78	0.79	0.58	0.11	0.83	<.001
3	Constant	—	—	–1.59	6.63	—	.81
	Sex	–0.09	0.14	2.38	3.71	0.16	.53
	MIP	0.45	0.46	0.34	0.16	0.52	.048

Abbreviations: MEP, maximum expiratory pressure; MIP, maximum inspiratory pressure.
[a] Sex is a dichotomous variable and was coded as 0 = male and 1 = female.

Discussion

The main finding of this study is that both MIP and MEP were correlated with HGF. The correlation of MIP with HGF was moderate, and the correlation of MEP with HGF was strong.

Tracheostomy is commonly performed in critically ill patients, especially those in need of prolonged mechanical ventilation because of acute respiratory failure and airway issues.[30] For this reason, the clinical condition of patients with tracheostomies may be more serious than that of other ICU patients. However, in studies by Lai et al[31] and Bragança et al,[32] the MIP, MEP, and HGF of patients with tracheostomies did not significantly differ from the MIP, MEP, and HGF of other patients in the ICU.

Measurement of HGF may provide a simple and accurate alternative to the Medical Research Council score for the diagnosis of ICU-AW.[32] In some studies, the mean (SD) expected HGF, depending on sex and age, was 33.1 (11.1) kg, whereas in our study the mean (SD) HGF was 11.4 (7.4) kg ($P < .001$).[33,34]

Men are considered to have ICU-AW when the HGF is less than 11 kg; the corresponding value for women is less than 7 kg.[35] According to this classification, 12 patients in our study had ICU-AW. The others had moderate weakness well below (<50% of) the reference value; for healthy people between 75 and 85 years old, normal HGF is 33.4 kg for men and 16.6 kg for women.[33,34]

In addition to HGF and the Medical Research Council sum score, MIP can be used to diagnose ICU-AW. A MIP threshold of 36 cm H_2O can indicate ICU-AW (sensitivity, 88%; specificity, 76%).[11,36] This fact suggests that ICU-AW involves all skeletal muscles.[11,37]

The strong correlation between HGF and MEP (which corresponds to the maximum strength of the abdominal and internal intercostal muscles, which participate in coughing) suggests that an individual who is able to grip the hand tightly can also cough. Thus a simple command to perform a strong handshake could serve as an indirect cough evaluation. Cough strength is a predictor of extubation outcome, morbidity, and mortality in patients in the ICU.[38] Additionally, forced vital capacity (a cough strength indicator) measured before extubation closely correlates with forced vital capacity after extubation and may serve as an objective predictor of postextubation respiratory failure.[39]

The moderate correlation between MIP and MEP may explain the interaction between these 2 indicators in patients with ICU-AW. Our result does not differ greatly from the result of a study by Park et al[40] in which MIP and MEP were significantly correlated in healthy patients ($r = 0.597$, $P < .001$).

Maximum inspiratory pressure, which is highly dependent on diaphragm strength, had a significant but weak correlation with the maximum force of peripheral skeletal muscles (ie, HGF) in critically ill patients in our study. This finding contrasts with the strong correlation that has been previously observed in healthy participants.[41] The reason for this discrepancy is probably that the diaphragm does not follow the same degenerative course as other skeletal muscles in patients with ICU myoneuropathy, possibly because in ICU patients the diaphragm is exercised during breathing but the peripheral muscles remain less active.

Both mean inspiratory pressure and mean expiratory pressure were correlated with handgrip force.

Our regression analysis provides additional information about the associations between HGF, MIP, and MEP when the confounding influence of sex is controlled for. Handgrip force was a significant predictor of both MIP and MEP. However, when MIP and MEP were combined in a single model, the predicting ability of MIP was lost, possibly because both MIP and MEP contribute substantially to the prediction of HGF. Maximum inspiratory pressure can predict HGF, but our results suggest that MEP is preferred for predicting HGF and accounts for much of the observed variance.

Our study has 2 clinical implications. In our study, HGF was correlated more strongly with MEP than with MIP in ICU patients (in the healthy population, MIP correlates strongly with HGF). This result may indicate that in patients with ICU-AW, diaphragm degeneration is delayed as compared with other peripheral muscles. In addition, a strong handhold (handgrip) could indicate a strong expiratory muscle system (MEP), so patients with a strong handhold may have a stronger cough.

Limitations

Because our study included more men than women, our findings are more applicable to men than to women. However, men generally outnumber women in the ICU, and most ICU patients with tracheostomies are also men.[42] Therefore, although our sample consisted mainly of men, it was representative of the ICU population.[43] We adapted our analysis to control for the confounding influence of sex because of the physical difference in grip strength between sexes, and our hierarchical regression model included sex in the first block of predictors.

Selecting patients with established ICU-AW (diagnosed either by HGF or by Medical Research Council sum score) would result in greater homogeneity in the study sample. We determined stages of ICU muscle weakness by using HGF and not the Medical Research Council sum score because HGF data were collected on the day MIP and MEP were measured. Measurement of Medical Research Council sum score requires only 1 assessor, whereas measurements of HGF are more reproducible among different examiners.

Conclusions

Cough strength is a predictor of extubation outcome, morbidity, and mortality, especially in patients in the ICU. Handgrip force and the strength of expiratory muscles involved in coughing are strongly correlated and most likely follow a parallel course in ICU-AW. A strong handhold could be an indication of a strong cough. Further studies with larger sample sizes, as well as empirical classification of HGF, are required to better characterize associations between HGF and patient outcomes.

FINANCIAL DISCLOSURES
None reported.

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