Bulletin of Faculty of Physical Therapy

ORIGINAL RESEARCH ARTICLE

Open Access

Upper limb muscle strength and exercise endurance as predictors of successful extubation in mechanically ventilated patients

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Abstract

Background Failed extubation increases the intensive care unit (ICU) length of stay, hospital length of stay, and financial costs and it reduces the patient's functional ability. Avoiding failed extubation is of utmost importance, therefore predictors for successful extubation are paramount.

Objective To determine if successful extubation in mechanically ventilated patients can be predicted by physiotherapists using upper limb muscle strength and exercise endurance.

Methods Fifty-seven patients from the medical and trauma ICUs of a large academic hospital were eligible for testing. Muscle strength was evaluated using the Oxford grading scale, Medical Research Council score (MRC score), handgrip dynamometer, and maximum inspiratory pressure (MIP). Exercise endurance was tested while the patient was actively riding the MOTOmed® letto2 cycle ergometer for six minutes with the upper limbs.

Results Exercise endurance (time the patient rode actively) ($P=0.005$), MRC-score ($P=0.007$), and number of days ventilated ($P=0.005$) were associated with successful extubation. The handgrip strength ($P=0.061$), MIP ($P=0.095$), and muscle strength of the sternocleidomastoid ($P=0.053$) and trapezius muscles ($P=0.075$) were marginally associated with successful extubation. Due to multicollinearity when developing the prediction equation, the final multivariable logistic regression prediction model included only exercise endurance and the number of days ventilated. The newly developed prediction equation conferred a sensitivity of 81.82% and a specificity of 77.14% to predict successful extubation.

Conclusion Successful extubation of mechanically ventilated patients can be predicted by physiotherapists using the newly developed prediction equation consisting of exercise endurance and number of days ventilated.

Keywords Intensive care unit, Mechanical ventilation, Predictors of successful extubation, Upper limb muscle strength, Exercise endurance

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Background

Since the inception of mechanical ventilators, successful weaning and extubation failure have always been a challenge that physiotherapists, nurses, and physicians grapple with [1]. Early liberation from the ventilator is beneficial to patients, yet premature discontinuation of mechanical ventilation can compromise gas exchange and lead to re-intubation [2]. Failed extubation is associated with an increase in intensive care unit (ICU) length of stay, hospital length of stay, increased cost, and an increase in mortality rate [3]. It can be due to congestive cardiac failure, upper airway obstruction, neurological impairment, an ineffective cough with airway secretions, or respiratory failure [1, 4]. Respiratory failure usually occurs when the load on the diaphragm and accessory respiratory muscles (trapezius, sternocleidomastoid, scalene, and pectoralis major muscles) exceed their capacity [5].

A physiotherapist plays an important role in managing the patient's respiratory system as well as the musculoskeletal system in the ICU. It is thus vital that physiotherapists are actively involved in the decision to extubate [6]. Physiotherapy-driven weaning protocols are safe and decrease the weaning time [7, 8].

Several studies have been performed to evaluate successful extubation predictors, but none can be used with absolute certainty or in isolation [1–3, 6, 9–11]. Parameters reflecting cardiovascular and respiratory function such as the fluid balance, pneumonia, amount of secretions, respiratory rate, heart rate variability, tidal volume, rapid shallow breathing index (RSBI), cough strength, partial pressure of arterial oxygen to fraction of inspired oxygen ratio (PaO_2/FiO_2 ratio), maximum inspiratory pressure (MIP), maximum expiratory pressure, diaphragmatic dysfunction and handgrip strength have been explored [1–3, 10–15]. None of these factors included exercise endurance. A study conducted by De Jonghe et al. [12] indicated that respiratory muscle weakness is associated with peripheral muscle weakness. Toosizadeh et al. [13] on the other hand concluded that upper extremity strength is associated with pulmonary function and exercise endurance tested with the 6-min walking test. A pilot study by De Beer et al. [14] demonstrated that the muscle strength of the deltoid, sternocleidomastoid, and trapezius muscles measured with the Oxford grading scale may possibly be associated with successful extubation. During the same study exercise endurance tested with the MOTOmed® letto2 cycle ergometer indicated a trend of possible association with successful extubation [14].

The possible associations between respiratory muscle strength, peripheral muscle strength, exercise endurance, and successful extubation raise the question of whether successful extubation can be predicted using upper limb muscle strength and exercise endurance as predictors [12–14]. The aim of this study was to determine if upper limb muscle strength and exercise endurance can predict successful extubation using a prediction equation.

Methods

Study design and population

A predictive correlational study was conducted for eighteen months at an Academic Hospital in Pretoria, South Africa. Ethical approval was obtained from the Research Ethics Committee, Faculty of Health Sciences, University of Pretoria (number 394/2017). Patients were recruited from the Surgery/Trauma and Medical ICUs.

All patients who were considered for extubation for the first time by the healthcare team according to the unit protocol (Table 1), were evaluated daily to determine if they complied with the inclusion criteria for the study. Inclusion criteria were age 18 years and older, mechanically ventilated for three and more days, understanding Afrikaans and/or English, awake and cooperative with Richmond Agitation-Sedation Scale (RASS) "-1, 0, 1" and 3/5 for the 5-point questionnaire. Hemodynamic stability with a heart rate ≤ 140b/min, systolic blood pressure ≥ 90 mmHg, hemoglobin ≥ 7 g/dl^{-1}, and a temperature < 38.5 °C. Minimal mechanical ventilator settings of continuous positive pressure ventilation, positive end-expiratory pressure (PEEP) ≤ 8 cmH_2O, $FiO_2 \leq 40\%$, $SpO_2 \geq 90\%$, and pH ≥ 7.35 were required. In addition, a good cough reflex to tracheal suctioning and minimal to moderate secretions (patients only suctioned four hourly according to unit protocol) were stipulated. The exclusion criteria were: patients with "do not resuscitate" status, upper airway obstruction, body mass index > 35 kg/m^2, cardiomyopathy, atrial fibrillation, primary/previously diagnosed neuromuscular disorder, psychiatric disorder, severe agitation (RASS $\geq +2$) or an acute asthma

Table 1 Unit extubation protocol

• Reversal of underlying cause of intubation
• Haemodynamic stability: HR < 140 b/min, Hb > 7 g/dl^{-1}, T < 38.5 °C, no or minimal vasopressor or inotropes
• CPAP, PEEP ≤ 8 cm H_2O, $FiO_2 \leq 40\%$, $SpO_2 \geq 85\%$, pH ≥ 7.35, $PaO_2/FiO_2 > 200$
• Adequate cough strength
• No neuromuscular blocking agents

attack. Patients who were not able to perform manual muscle testing techniques due to a spinal cord injury, bilateral amputations, bilateral fractures, soft tissue injuries, burns, or dressings limiting the testing of the muscle strength were also excluded.

All patients recruited in the study received usual physiotherapy treatment. The treatment included chest physiotherapy and rehabilitation (mobilization and active or passive upper limb and lower limb exercises). All patients included in the study gave informed consent.

Study procedures

The demographic and clinical characteristic information, muscle strength, exercise endurance, and MIP data were collected by the principal researcher. Patients considered for extubation were evaluated daily for awareness and orientation by using the RASS [15] and a 5-point questionnaire [12]. The RSBI, electrolytes, and PaO_2/FiO_2 ratio were documented before muscle strength testing was commenced. The Medical Research Council score (MRC score) was used to evaluate the patient's general muscle strength. The muscle strength of the deltoid, sternocleidomastoid, trapezius, and pectoralis major muscles was evaluated with the Oxford grading scale. Muscle testing started within the position of a grade 3 muscle and then adapted according to the patient's ability to include or illuminate the influence of gravity [16, 17].

After completing the muscle strength testing, the patients were positioned in an upright position in bed with arms by side and elbows 90° flexed to test the handgrip strength with the handgrip dynamometer. The forearm was allowed to rest on the thigh. For all patients, the maximum contraction was determined as the highest of the three contractions. The dynamometer handle was in the second position as described by published recommendations from the American Society of Hand Therapists [18]. One-minute rest periods were present between contractions. The dominant and non-dominant hands were tested. The handgrip dynamometer and cycle ergometer were automatically calibrated before each test.

After the handgrip assessment, exercise endurance was tested with the MOTOmed® letto2 cycle ergometer. Patients were positioned in the semi-Fowler's position in bed with their upper limbs placed in the forearm shells with arm cuffs. Patients rode the cycle ergometer for six minutes with the upper limbs against a resistance of one gear (1 gear = 0.85 kg) while using the Servo Cycle program [19]. The time and distance the patient rode actively (pushing the pedals themselves) as well as passively (machine is moving the pedals) were documented.

Patients remained in the semi-fowler's position in bed for the MIP measurements. The manometer was connected to the endotracheal tube/tracheostomy. The best measurement out of three was used in the study. Patients rested for a minimum of five minutes or until their heart rate and oxygen saturation were back to baseline between positional changes (sitting to supine) and the different tests. Patients also had to respond to the qualitative question whether they were comfortable or not, before any test was commenced. Testing was discontinued immediately when a patient developed any sign of hemodynamic instability (any changes of 20% of the baseline heart rate, blood pressure, or oxygen saturation) [9, 20] or if the heart rate, blood pressure, or oxygen saturation did not return to baseline after 5 min.

All patients started with the extubation process 30 min after completion of the muscle strength and endurance tests. Patients are evaluated at 48 h and 72 h post-extubation in order to determine whether the patient was successfully extubated. The research process is demonstrated in Fig. 1.

Statistical analysis

The statistical objective of this study was to develop a prediction equation based on upper limb muscle strength (deltoid, sternocleidomastoid, trapezius, and pectoralis major muscles) and exercise endurance (distance rode actively) for the outcome of extubation. Continuous data was summarised using mean, standard deviation, median, interquartile range, and 95% confidence intervals. For discrete parameters frequency, percentage, cross-tabulation, and 95% confidence intervals were reported. Univariable analyses were done to assess the association of the observed factors with extubation outcomes. For continuous data use, Student's two-sample *t*-test while for discrete data Pearson's chi-square test and univariable logistic regression were employed. The purpose of the univariable analysis was to identify possible factors (marginal significant and significant factors) for inclusion in a multivariable logistic regression analysis to develop the prediction equation. In the modeling process factors which were no longer significant in the multivariable model dropped out, multicollinearity among factors was also responsible for dropout. The predictive ability of the prediction equation was assessed in a cross-validation. Testing was based on a 0.05 level of significance. $P \leq 0.05$ was regarded as statistically significant, $0.05 < P \leq 0.1$ was marginally significant and $P > 0.1$ was not significant. Data analysis employed STATA version 15.1 software [21]. The outcome of extubation was referred to and divided into successful extubation and failed extubation.

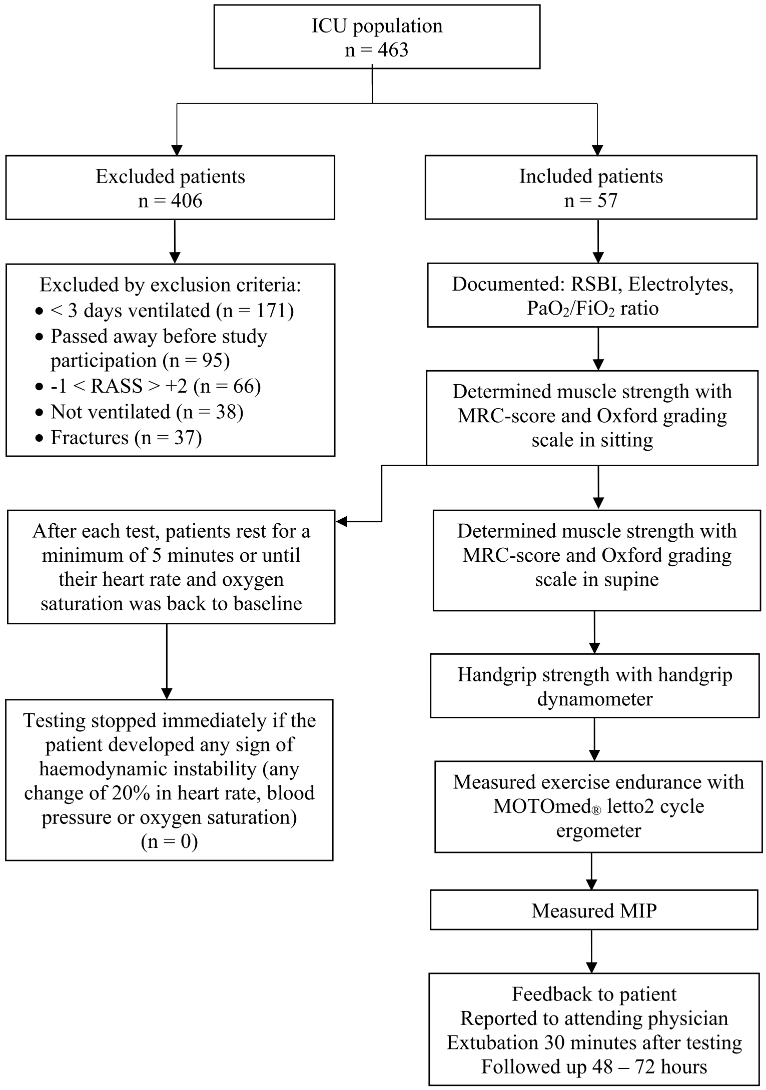

Fig. 1 Research process

Table 2 Demographic data of the cohort

Variable	Successful extubation *n* = 35	Failed extubation *n* = 22	*P* value
Male	19 (55.9%)	15 (44.1%)	0.407
Female	16 (69.6%)	7 (30.4%)	0.407
Age	43.171 (14.475)[a]	47.455 (17.522)[a]	0.321
Number of days ventilated	5.714 (3.304)[a]	7.754 (6.197)[a]	0.001

[a] Mean (*SD* Standard deviation)

Results

A total of 463 patients were recruited but only 57 patients were eligible for inclusion data analysis (Fig. 1). All the included patients completed the assessment. No adverse events were reported. Table 2 outlines the demographic data of the 57 patients. Seven female (30.4%) and 15 male (44.1%) participants failed extubation. Gender and age were not statistically significantly associated with successful extubation. The diagnosis of the patients included medical (asthma, congestive cardiac failure, renal failure, organophosphate poisoning), and surgery (abdominal surgery, poly-trauma, vascular surgery, orthopedic surgery, urology, gynecology) conditions.

Successfully extubated patients had a marginally significant greater proportion of grade 3 muscle strength of sternocleidomastoid ($P = 0.058$: 71.4% vs 45,5%) and trapezius ($P = 0.095$: 94.3% vs 77.3%) muscles than

Table 3 Univariable logistic regression of variables

Variable	Odds ratio/ relative risk[b]	95% conf. interval	*P* value
Sternocleidomastoid muscle	3	0.984–9.144	0.053
Trapezius muscle	4.853	0.851–27.679	0.075
Deltoid muscle	1.929	0.596–6.235	0.273
Pectoralis major muscle	1.715	0.583–5.047	0.327
MRC-score	0.931	0.884–0.980	0.007
Handgrip strength	0.943	0.887–1.003	0.061
MIP	1.148	0.976–1.351	0.095
Time rode actively[a]	0.994[b]	0.990– 0.998	0.005
Time rode passively[a]	1.006[b]	1.002–1.010	0.007
Active distance covered	0.161[b]	0.035–0.735	0.018
Resting heart rate	1.051[b]	0.998–1.108	0.060
Heart rate post-testing	1.041[b]	0.989–1.096	0.127
Systolic blood pressure	1.001[b]	0.972–1.030	0.956
Diastolic blood pressure	1.036[b]	0.987–1.087	0.157
RSBI	1.030[b]	1.006–1.057	0.031
PaO_2/FiO_2 ratio	0.994[b]	0.987–1.001	0.102
Days ventilated	1.242[b]	1.068–1.444	0.005
RASS	0.115	0.130–1.027	0.053

[a] 15 s units

[b] relative risk value

failed extubated subjects. The muscle strength of the deltoid ($P = 0.366$) and pectoralis major ($P = 0.417$) muscles were not significantly associated with successful extubation. Logistic regression analysis for the upper limb muscle strength in Table 3 reflected that the sternocleidomastoid and trapezius muscles were marginally significantly associated with successful extubation.

The mean body muscle strength, tested with the MRC score, was significantly greater in the successfully extubated group (Table 4). A one-point increase in the MRC score was associated with a (7%) reduction in the risk of failing extubation. The extubation groups were marginally significantly different with regards to the mean handgrip strength measured with the handgrip dynamometer and respiratory muscle strength measured with the MIP respectively.

Successfully extubated patients rode the cycle ergometer significantly longer by themselves (actively) than the failed extubated subjects (Table 4). The logistic regression analysis in Table 3 indicates that for every 15 s that the subject rode actively on the cycle ergometer with the upper limbs, their relative risk of failing extubation decreased by 5%. Post-testing the successfully extubated patients did not differ significantly from the failed extubated subjects with respect to mean heart rate (% of maximum heart rate) ($P = 0.125$: 54.8% vs 59.4%). The resting heart rate was marginally associated with successful extubation whereas the systolic and diastolic blood pressure measurements were not significantly associated with successful extubation (Table 4). The continuous data in Table 4 showed that the RSBI is significantly associated with successful extubation but the PaO_2/FiO_2 ratio and RASS were only marginally significantly associated with successful extubation. Successfully extubated patients were ventilated for shorter times. Every day a patient was ventilated, the higher the relative risk (RR = 1.242) was to fail extubation.

To develop a prediction equation for predicting successful extubation a multivariable logistic regression was employed. The sternocleidomastoid muscle strength, MRC score, exercise endurance (time rode actively on the cycle ergometer), number of days ventilated, and RSBI were included as significant exposure factors. Factors were considered at the liberal 0.10 level of significance. The MRC score and exercise endurance were strongly correlated ($r = 0.7247$; $P < 0.001$) and the linear relationship was found as MRC-score = 26.97 + 0.062 × exercise endurance (active time rode). The MRC-score and handgrip strength also correlated ($r = 0.5323$; $P < 0.001$) and the linear relationship was found as MRC-score = 32.01 + 0.610 × handgrip strength. The handgrip strength and exercise endurance correlated ($r = 0.5276$; $P < 0.001$) with a lower correlation coefficient than the MRC-score and exercise endurance.

Due to the multicollinearity, the final multivariable logistic regression prediction model included only the exercise endurance (active time the patient was riding in 15-s units) and the number of days ventilated (Table 5) as the other factors did not add to the predictive value of the model. This model conferred a sensitivity of 81.82% and a specificity of 77.14% for a 0.43 cut-off in the probability of a poor extubation outcome.

The predictive ability of the newly developed tool was assessed using cross-validation for the latter best equation, based on the number of days ventilated and exercise endurance respectively. The calculations demonstrated that if the equation, $\hat{y} = -1.0064 - (0.17 \times \text{active time}) + (0.230 \times \text{ventilator days})$, is used and the value for $\hat{y}$ is less than or equal to -0.282, the model has a sensitivity of 81.8% (Table 6) to predict successful extubation.

The electrolyte data was documented as part of the clinical data. All the values for the electrolytes were within normal limits and did not influence the extubation outcome.

Table 4 Student two-sample *t*-test of variables

Variable	Extubation outcome	Mean (SD)	95% conf. interval	*P* value
MRC-score	Successful	42.514[a] (9.642)	39.202–45.826	0.003
	Unsuccessful	32.909[a] (13.815)	26.784–39.034	
Handgrip strength	Successful	13.314[b] (12.129)	9.148–17.481	0.052
	Unsuccessful	7.682[b] (6.841)	4.649–10.715	
MIP	Successful	− 19.857[c] (6.459)	− 22.076– − 17.639	0.089
	Unsuccessful	− 17[c] (3.678)	− 18.829– − 15.171	
Active time rode	Successful	236.743[d] (135.380)	190.238– − 283.248	0.003
	Unsuccessful	122.091[d] (132.274)	63.444–180.738	
Passive time rode	Successful	121.829[d] (134.271)	75.705–167.952	0.004
	Unsuccessful	230.818[d] (133.969)	171.420–290.217	
Active distance covered	Successful	0.628[e] (0.534)	0.443–0.813	0.012
	Unsuccessful	0.286[e] (0.367)	0.124–0.449	
Passive distance covered	Successful	0.198[e] (0.221)	0.122–0.274	0.006
	Unsuccessful	0.370[e] (0.222)	0.272–0.468	
Resting heart rate	Successful	51.241[f] (11.520)	47.284–55.198	0.055
	Unsuccessful	57.126[f] (10.227)	52.592–61.660	
Heart rate post-testing	Successful	54.756[f] (11.442)	50.827–58.688	0.125
	Unsuccessful	59.412[f] (10.208)	54.886–63.938	
Systolic blood pressure	Successful	133.629[g] (20.084)	126.730–140.528	0.957
	Unsuccessful	133.909[g] (16.653)	126.526–141.293	
Diastolic blood pressure	Successful	71.914[g] (11.444)	67.983–75.845	0.154
	Unsuccessful	76.500[g] (12.011)	71.175–81.825	
RSBI	Successful	35.486[h] (18.421)	29.158–41.813	0.018
	Unsuccessful	50.941[h] (29.713)	37.767–64.115	
PaO_2/FiO_2 ratio	Successful	298.657 (71.388)	274.135–323.178	0.098
	Unsuccessful	262.095 (89.429)	221.388–302.803	
Days ventilated	Successful	5.714[i] (3.304)	4.579–6.849	0.001
	Unsuccessful	7.754[i] (6.197)	7.377–14.623	

[a] Score out of 60

[b] Measured in kg

[c] Measured in cmH_2O

[d] Time in seconds

[e] Distance in km

[f] Measured in b/m

[g] Measured in mmHg

[h] fR/VT = breaths/min.L

[i] Number of days

Table 5 Multivariable logistic regression: predictive equation model

Variable	Relative risk	Coef	95% conf. interval	*P* value
Active time (15 s units)	0.899	− 0.107	0.834–0.969	0.005
Days ventilated	1.258	0.230	1.062–1.491	0.008

Discussion

Successfully predicting extubation is difficult as it is confounded by many factors. We have observed that successful extubation in critically ill mechanically ventilated patients may be predicted based on exercise endurance and duration of ventilation.

We measured exercise endurance according to the time the patient rode the MOTOmed® letto2 cycle ergometer actively with the upper limbs. Using the upper limb cycle ergometer for six minutes is aligned with both Hol et al. [22] and Bulthuis et al. [23] who recommend the 6-min

Table 6 Diagnostic statistics of the prediction model after cross-validation and sensitivity and specificity of prediction model with $\hat{y} \leq -0.282$ percentage (95% confidence interval)

Diagnostic statistics	Prediction model after cross-validation 39% (26%; 52.4%)	Prediction model with $\hat{y} \leq -0.282$ 39% (26%; 52.4%)
Sensitivity	77.3% (54.6%; 92.2%)	81.8% (59.7%; 94.8%)
Specificity	74.3% (56.7%, 87.5%)	77.1% (59.9%; 89.6%)
Positive predictive value	65.4% (44.3%; 82.8%)	69.2% (44.3%; 85.7%)
Negative predictive value	83.9% (66.3%; 94.5%)	87.1% (70.2%; 96.4%)
ROC area	0.758 (0.642; 0.874)	0.795 (0.686; 0.903)

arm test (6-MAT) with a cycle ergometer to determine exercise endurance. Hol et al. [22] used the 6-MAT on spinal cord injured patients whereas Bulthuis et al. [23] used it among 30 healthy volunteers. To our knowledge, our study is the first that has included more than 30 patients when evaluating exercise endurance with an arm ergometer in the ICU setting. The training intensity of our patients was 54% of the patients' maximum heart rate. This is in accordance with Swain et al. [24] and the American College of Sports Medicine (cited Swain et al.) who suggest that a 70 to 30% heart rate reserve is required to produce an exercise training effect and result in improved aerobic capacity in unfit people. Evaluating exercise endurance can be challenging when not performed in a laboratory where the VO_2 max can confirm a change in the training intensity and aerobic capacity. Exercise endurance indicates whether a patient has sufficient maximal oxygen uptake to perform an activity. Riding the cycle ergometer with the upper limbs causes a higher oxygen uptake, heart rate, and pulmonary ventilation than riding with the lower limbs [24]. According to Mitropoulos et al. [25] there is an increase in anaerobic metabolism, greater carbohydrate oxidation, lactate release, and lower oxygen extraction capacity in the arms than in the legs. An increase in the cardiac output during exercise increases oxygen uptake by the working muscles as well as increases blood flow to the lungs [26]. Transitioning to spontaneous breathing after extubation increases the work of breathing and myocardial oxygen consumption [27, 28]. Evaluating exercise endurance should therefore assist the physiotherapist in determining their cardiorespiratory reserve to tolerate spontaneous breathing.

Our successfully extubated patients demonstrated a greater proportion of grade 3 sternocleidomastoid and trapezius muscle strength than patients who failed extubation. The sternocleidomastoid and trapezius muscle are important when the ventilator demands increase [29]. When their muscle strength increases, the diaphragm functions better. Critically ill patients often fixate their neck/cervical spine which can lead to contraction of the trapezius and sternocleidomastoid muscles. The sternocleidomastoid and trapezius muscles might therefore have a grade 3 muscle strength and could explain why there are some associations with successful extubation.

The deltoid muscle is responsible for shoulder abduction whilst the pectoralis major muscles can contract during forced expiratory tasks [29]. Vivier et al. [30] showed that pectoral muscle atrophy was associated with prolonged weaning from mechanical ventilation. During mechanical ventilation, the work of breathing is decreased due to pressure support given by the ventilator. The decrease in the negative pressure also causes a reduction in the cough strength [30]. The correlation between the electromyographic activity of the pectoralis major muscle and the peak expiratory flow, the decreased work of breathing, and the weak cough might indicate that the pectoralis major muscle function is also decreased. We recommend that future studies explore the correlation between pectoralis major muscle strength and cough strength. The deltoid and pectoralis major muscles consist mainly of fast-twitch muscle fibres and their inactivity might lead to muscle atrophy occurring explaining why they are not associated with successful extubation. A decrease in pectoralis major muscle strength did not influence our patients while riding the cycle ergometer. As outlined by Mitropoulos et al. [25] this might be because during arm cycle ergometry the primary working muscles are the biceps and triceps brachii muscles.

Patients with a higher MRC score were more likely to be successfully extubated. Similarly, Dres et al. [31] found that failed extubation was associated with significantly lower MRC scores and that the MRC score is not independently associated with weaning failure. Although our results demonstrated that the MRC-score was associated with extubation failure, our final multivariable logistic regression prediction model also did not merit its inclusion. In view of the correlation between the MRC score, handgrip strength and exercise endurance there was multicollinearity when developing the prediction equation, hence the inclusion of exercise endurance only. Our correlation between the MRC score and handgrip strength has been previously described by Yosef-Brauner et al. [32].

Unlike our marginal association, Cottereau et al. [33] found no association between handgrip strength and extubation outcome. They explain that the handgrip strength evaluation does represent patients with predominant proximal muscle weakness and not distal hand weakness [33]. Interestingly, Efstathiou et al. [34] demonstrated a strong correlation between MIP and handgrip strength. These differences in findings, maybe due to sample size variations. Cottereau et al. [33] evaluated 84 patients whereas our study and Efstathiou et al. [34] evaluated 57 and 24 subjects respectively. As such we recommend that future research explore factors such as hand dominancy or oedema that might influence handgrip strength or its assessment.

Our observation that successful extubation was associated with RSBI and MIP (only marginally) contrasts with others [35, 36] where MIP has demonstrated greater predictive precision than RSBI. Including the RSBI in the multivariable logistic prediction model in our model conferred a sensitivity of 86.36% and specificity of 80%. However after cross-validation, the predictive model (RSBI, exercise endurance, and number of days ventilated) exhibited a sensitivity of 68.2% and specificity of 74.3%, and thus RSBI was excluded. RSBI is the most studied parameter and RSBI < 105 b/min is a good predictor for weaning, but not when used in isolation [37]. Variable results regarding MIP and RSBI as predictors may be due to the MIP being difficult for patients to perform, whilst the RSBI is a computation. For critically ill patients, the MIP test may not be practical to implement and interpret.

Our findings that the number of days ventilated is associated with successful extubation have also been described by Thille et al. [38] and Baptistella et al. [37] who observed that the longer the patients are ventilated, the higher the risk for extubation failure.

Currently utilized predictors focus mainly on respiratory factors. Our model adds to this by considering the functionality of the respiratory, cardiovascular, and musculoskeletal systems which are inextricably linked to achieving successful extubation [39]. We thus argue that our model would be very useful as an additional tool to inform the decision process for extubation.

Limitations

As a single center study conducted in medical and general surgical patients, this limits the findings to this subset of critically ill patients. Further, participants were exposed to the handgrip dynamometer or cycle ergometer for the first time during the course of the study.

Recommendations

We recommend that our prediction model be externally validated in medical and surgical ICU settings. We also recommend exploration of the association between cough strength and successful extubation as well as the association between MIP and upper limb muscle strength.

Conclusion

This study has demonstrated that successful extubation of mechanically ventilated patients may be predicted by using the newly developed prediction equation which incorporates exercise endurance and number of days ventilated. This tool adds to the array of available methods to assist the multidisciplinary healthcare team in determining readiness for extubation. This is the first study that combines cardio-respiratory and muscle function to evaluate extubation success. Essentially we conclude that as the number of days the patient is ventilated increases and the exercise endurance reduces the risk of failing extubation increases. Taking into account the benefits of successful extubating, the findings of this study have the potential to impact positively on patient outcomes.

Abbreviations

ICU	Intensive care unit
ICU-AW	Intensive care unit acquired weakness
MRC-score	Medical Research Council score
MIP	Maximum inspiratory pressure
PaO_2/FiO_2 ratio	Partial pressure of arterial oxygen to fraction of inspired oxygen ratio
PEEP	Positive end-expiratory pressure
RSBI	Rapid shallow breathing index
RASS	Richmond Agitation Sedation Scale

Acknowledgements

We thank the staff of the participating intensive care units.

Authors' contributions

CRdBB contributed to the literature search, data collection, study design, and manuscript preparation. AJvR contributed to the study design and review of the manuscript. PJB analyzed the data. FP reviewed the manuscript. AJvR supervised and FP co-supervised the study. All authors read and approved the final manuscript.

Funding

The principle researcher received a research grant of 20,000 (ZAR) from the Critical Care Society of South Africa.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Research Ethics Committee, Faculty of Health Sciences, University of Pretoria in 2017 (number 394/2017). All patients included gave informed consent to participate. Permission to conduct the study was also obtained from the CEO of Steve Biko Academic Hospital as well as the head of the Critical Care and Physiotherapy departments of the hospital respectively. The study complies with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Received: 10 October 2023 Accepted: 1 February 2024
Published online: 22 May 2024

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