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Effects of structured protocolized physical therapy on the duration of mechanical ventilation in patients with prolonged weaning

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A R T I C L E I N F O

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A B S T R A C T

Purpose: 20% of patients with mechanical ventilation (MV) have a prolonged, complex weaning process, often experiencing a condition of ICU-acquired weakness (ICUAW), with a severe decrease in muscle function and restricted long-term prognosis. We aimed to analyze a protocolized, systematic approach of physiotherapy in prolonged weaning patients and hypothesized that the duration of weaning from MV would be shortened.

Methods: **ICU** patients with prolonged weaning were included before (group 1) and after (group 2) introduction of a quality control measure of a structured and protocolized physiotherapy program. Primary endpoint was the tested dynamometric handgrip strength and the Surgical Intensive Care Unit Optimal Mobilization Score (SOMS). Secondary endpoints were weaning success rate, ventilator-free days, hospital mortality, the prevalence of ICUAW, infections and delirium.

Results: 106 patients were included. Both the SOMS and the handgrip test were significantly improved after introducing the program. Despite no differences in weaning success rates at discharge, the total length of MV was significantly shorter in group 2, which also had lower prevalence of infection and higher probability of survival.

Conclusions: Protocolized, systematic physiotherapy resulted in an improvement of the clinical outcome in patients with prolonged weaning. Results were objectifiable with the SOMS and the handgrip test.

1. Introduction

Mechanical ventilation (MV) is a central pillar of modern intensive care medicine used primarily to treat acute respiratory insufficiency and to bridge the time until the cause of respiratory insufficiency is resolved. Particularly invasive MV is rapidly associated with secondary complications like ventilator-induced lung injury (VILI), ventilator-induced diaphragmatic dysfunction (VIDD), and ventilator-associated pneumonia (VAP) [1-3]. Special attention must be paid to weaning from MV at the earliest stage, which is especially true for patients in whom weaning is protracted because they have already had a longer intensive care stay. Typical risk factors include advanced age, complex surgical procedures with resulting complications, and severe comorbidities in particular cardiac and pulmonary conditions with chronic ventilatory insufficiency.

Up to 60% of mechanically ventilated ICU patients can be successfully weaned in the first attempt whereas the remaining percentage fails the first spontaneous breathing trial (SBT) and may require up to 3+ SBTs or up to 7+ days from the first attempt to achieve successful weaning [4]. These categories as defined by Boles et al. [5] help address the most complex patient group of prolonged weaning often requiring complex, multimodal, multi-professional and protracted concepts and treatment in specialized weaning centers [6].

Patients with prolonged weaning often experience a condition known as ICU-acquired weakness (ICUAW), which is a common problem following acute illness and may be caused by factors such as inflammation, oxidative stress, and immobilization. ICUAW is characterized by a severe decrease in muscle function, resulting in both prolonged treatment and restricted long-term prognosis [10-12]. While the best possible recovery of respiratory and peripheral musculature is quite

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important in being weaned from MV, optimization of cognitive function, cardiac situation and hemodynamics, nutrition and last but not least psyche and motivation also contribute to the successful weaning from MV.

When ICUAW is occurring, an early, structured and protocolized approach of physical activity could result in improved outcome in ICU patients. However, only a few studies with limited evidence have been performed to date on assessing prevention strategies for ICUAW [12]. In a recent study, the effects of early active mobilization in mechanically ventilated ICU patients did not show positive effects on mortality and hospital discharge [13]. It could stand to reason that an active approach not only needs to start early to be effective but also the strategy should be structured and protocolized to objectively measure the effects of physical activity and avoid adverse events (e.g., disconnection of catheters or tubes, hemodynamic instability, etc.) in such prolonged weaning ICU patients.

This study, therefore, aims to analyze a protocolized and systematic approach of physical activity in patients with prolonged weaning and hypothesizes that muscle strength would be improved, and consequently, the duration of weaning from mechanical ventilation would be shortened with such an approach.

2. Material and methods

2.1. Weaning unit

The interdisciplinary weaning unit (WEA) of the University Hospital RWTH Aachen, Germany, is a separate ICU infrastructure and consists of 18 beds in total. It is technically fully equipped to provide complete organ support (i.e., invasive and non-invasive ventilation (NIV), intermittent dialysis, and vasopressor therapy). A team of certified senior physicians, nurses, physiotherapists, respiratory therapists, speech therapists and one psychologist covers the complete care of patients with prolonged weaning, being referred from surgical and medical inhouse ICUs, but also from external hospitals.

Admission criteria to the WEA include the absence of acute illness and multi-organ failure, absence of high-dosage or multiple vasopressor therapy, and the absence of continuous renal replacement therapy (RRT). Intermittent RRT can be performed. If a patient deteriorates (e.g., due to recurrent infection) and for example one vasopressor is needed, this can also be handled on the WEA. If weaning from MV is no longer a clinical focus due to recurrent critical illness, a re-transfer to our ICU is also possible at any time. The surgical treatment, especially multistage procedures that require repeated performance of general anesthesia, should be preferably completed prior to admission. A previously performed tracheostomy not shorter than 24 h and a documented spontaneous breathing trial (SBT) (including reasons for withdrawal) as well as consideration of assessing readiness to wean, [5] respectively, on the ICUs are further admission criteria for the WEA.

The weaning process is carried out systematically according to the German S2k-Guideline ‘Prolonged Weaning’ [6]. Weaning subcategories according to the German S2k-Guideline for prolonged weaning, category 3 after Boles et al., are defined as follows:

- 3a: Successful weaning after at least three failed SBT or MV longer than 7 days after the first failed SBT without the use of NIV.
- 3b: Successful weaning after at least three failed SBT or MV longer than 7 days after the first failed SBT in combination with NIV; if necessary, continued into out-of-hospital (home) MV.
- 3c: Weaning failure: indication for permanent, invasive home ventilation or death during the process of prolonged weaning.

2.2. Study design and patient selection

This current study was an observational study after the introduction of routine medical quality control. The study received approval from the Institutional Review Board for Human Studies at the Medical Faculty of the University Hospital Aachen, Germany (# EK 122/13), and the need for informed consent was waived. All patient data were pseudonymized. All analyses were conducted according to the principles of the Declaration of Helsinki.

Data were collected before and after a quality improvement strategy. The first data collection period (01/2018–10/2018: phase 1, group 1 without systematic protocol) served to evaluate the actual state of physiotherapy care without protocol and/or objective measurements. In this group, all mobilizable patients in prolonged weaning received specialized physiotherapy treatment once *or* twice a day if specifically indicated.

After implementation of further personnel for systematic protocols (i.e., structured therapy after SOMS (see below), systematic respiratory physical therapy, limb control training, improve training for trunk and lower extremity muscle strength, planned double treatment daily) and routine performance of objectifiable tests (see below), a second data collection period (04/2019–12/2019: phase 2, group 2 with systematic protocol) was performed. The study flow is also depicted in Fig. 1.

Inclusion criteria were: sedation-free, cooperative, tracheotomized patients with $\geq$ 18 years of age, classified within the category of prolonged weaning (Boles et al. 2007). Patients with the occurrence of at least one of the following clinical characteristics were excluded: coma, increased intracranial pressure, need for sedatives, tetraplegia, unstable fractures, neuro-muscular diseases with involvement of respiratory muscles, and hemodynamic instability. Also, patients without prolonged weaning and patients being admitted from external hospitals were excluded due to incomplete data.

The primary endpoint of the study was the objective muscle strength measured by the Surgical Intensive Care Unit Optimal Mobilization Score (SOMS) and the handgrip strength (see below). Secondary endpoints were weaning success rate and ventilator-free days (defined as days on the WEA without any ventilatory support within 24 h), hospital mortality, and the prevalence of the following diagnoses within the course of treatment: ICUAW (as clinically diagnosed by a consulting neurologist), infection on the WEA (diagnosed by the attending intensivist and after local standardized operating procedures, including VAP (diagnosed using the Clinical Pulmonary Infection Score [CPIS] [7] and/or septic pneumonic shock (according to the American College of Chest Physicians [ACCP] / Society of Critical Care Medicine [SCCM] consensus criteria [8]), and delirium (diagnosed using the Confusion Assessment Method for the ICU (CAM-ICU) [9]).

2.3. Data collection

Data was retrieved retrospectively from an electronic patient record system (medico//s, Siemens, Germany) and an online patient data management system (IntelliSpace Critical Care and Anesthesia, ICCA Rev. F.01.01.001, Philips Electronics, Netherlands). Demographic data on age, sex, pre-disposing risk factors (i.e., diabetes mellitus, arterial hypertension, hyperlipidemia, smoking), pre-existing COPD, asthma bronchiale, pre-existing coronary artery disease (CAD), pre-existing neuro-muscular diseases, ICU admission criteria and diagnoses, ICU length of stay (LOS), need for renal replacement therapy (RRT), length of RRT, Simplified Acute Physiology Score (SAPS II) at ICU admission, Sequential Organ Failure Assessment Score (SOFA) were additionally collected.

The following data about treatment in the WEA was also extracted: SAPS II and SOFA at WEA admission, the prevalence of infection, delirium, adverse events (pulmonary embolism, thrombosis, acute bleeding events), need for and dosage of vasopressors, length of MV, ventilator-free days, weaning success (or failure) categorized after Boles et al. at the time of WEA discharge, total LOS in the hospital, mortality on the WEA.

The SAEHAN DHD-3 Digital Hand Dynamometer (SH1003, Saehan Industries (Germany) GmbH), including G-STAR™ Testing Software,

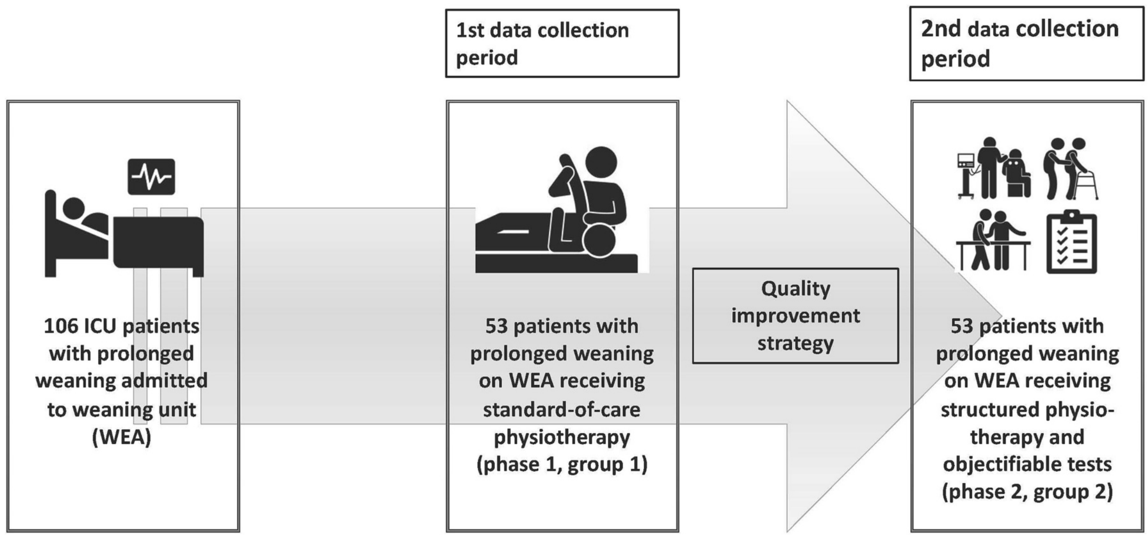

Fig. 1. Study design.
Patients and their data were collected before and after a quality control measure. A total of 106 patients was included, 53 in each group.

was used to measure hand grip strength. The medical device was CE certified (2195 CE) and approved by the Medical Devices Officer of the University Hospital of RWTH Aachen. The hydraulic hand dynamometer consists of a base, an adjustable handle with 4 grip positions and a digital LCD display that digitally displays grip force measurement results from 0 to 90 kg. The strength of the right and left hand were measured consecutively, if both measurements were possible. The initial hydraulic hand strength measurement (*first assessment*) was performed on the day of the patient's first contact with the physiotherapist on the WEA and the last measurement (*final assessment*) on the day of WEA discharge. Hand strength was additionally tested every 48 h after the first assessment.

Likewise, the Surgical Intensive Care Unit Optimal Mobilization Score (SOMS) was measured. It was previously described and validated by Meyer et al. 2013 and has been introduced as an evidence-based standardized physiotherapy algorithm for early mobilization of patients in prolonged weaning. The German version was also validated in clinical trials [14].

The numerical scale of the SOMS algorithm contains five levels and ranges from "0 - no activity" to "4 - walking". SOMS level 0 means that no mobilization is possible at all. A patient is evaluated with a SOMS of level 1 when the physical therapist can perform passive range-of-motion exercises on the patient in bed. SOMS level 2 indicates that sitting upright without support at the edge of the bed or in an armchair is possible. SOMS level 3 indicates that the patient is able to stand with or without support. The highest value SOMS level 4 records the patients` ability to walk.

SOMS was also tested as a first assessment after admission to WEA, daily, and within a final assessment.

2.4. Statistical analysis

Statistical analysis of data was carried out using the SAS® Version 9.4 program (SAS Institute Inc., USA). The electronic recording of the data was done with Microsoft® Excel® 2021 Version 16.50 (Microsoft Germany).

Continuous variables were expressed as mean values ± standard deviation. For the categorical (=qualitative) variables, absolute and relative frequencies were given. Statistical significance was tested after the following procedure: differences between continuous variables were evaluated using the double *t*-test for independent samples. If the populations had unequal variance, Satterthwaite's t-test was used instead. Categorical variables were compared using the Chi-square test or Fisher's exact test. Differences at the $\alpha = 0.05$ significance level were assumed to be significant.

Multivariate logistic regression analysis was performed to examine the impact of physical therapy as well as other risk factors on hospital mortality. Fourteen independent variables were included into the analysis: age, gender, duration of treatment in the weaning ward, internal vs. surgical admission, CHD, COPD, sum of SAPS II and TISS-10 scores on admission to the weaning ward, duration of ventilation, vasopressor requirements in the weaning ward (classified by 3 severity levels), need for renal replacement therapy in the weaning ward, diagnosis of ICU-acquired weakness, delirium, or infection during the course, and group membership in the 2 physiotherapy strategies studied. The global null hypothesis that all influencing variables did not contribute to explaining mortality versus the alternative hypothesis that at least one of the influencing variables had an impact was tested by the chi-square test. Subsequently, all variables with no relevant influence on the probability of dying in the hospital were eliminated using backward elimination with a significance level of $\alpha < 0.2$. The remaining variables were included in the final model. The null hypothesis that all included variables had an odds ratio (OR) of $OR = 1$ was tested using a Wald test with significance level $\alpha = 0.05$. The linearity in the logit was checked using the Box-Tidwell test. The possible presence of multicollinearity was discussed and excluded using a correlation matrix.

To evaluate the measured values of the hydraulic hand strength measurement (in 0.1 kg scaling), the minimum and maximum measured hand strength values of the right and left hand and the average difference between minimum and maximum values were recorded. To compare the improvement in hand strength due to increased physiotherapy treatment in both groups, the mean ± standard deviation of the maximum measured hand strength values of the left and right hands of both groups were calculated. The proportion of patients with no improvement in hand strength was expressed as a relative frequency. The quotient of the number of days between the initial assessment and final assessment and the average difference between minimum and maximum value was calculated (days/difference Min Max).

The evaluation of the SOMS score included the recording of the minimum and maximum SOMS values. To collect the degree of improvement in patients' mobility, the average difference between minimum and maximum SOMS values was calculated. To identify the patients without improvement, the initial SOMS readings were compared with the final readings, and the proportion of patients without improvement was expressed as a relative frequency. In addition, the quotient of the number of days between the initial and final assessment and the average difference between minimum and maximum value was calculated (days/difference Min Max).

3. Results

A total of 232 tracheotomized patients with prolonged weaning were treated in the WEA over the study period. 126 were excluded due to analgosedation or stress shielding due to delirium; 106 patients met the inclusion criteria and were accordingly analyzed. In each phase (group), 53 patients were treated. Demographic data and ICU patient characteristics are summarized in Table 1. No significant differences between the groups were detectable. The percentange of admission to the WEA from medical or surgical disciplines were comparable in both phases (phase 1: 45% vs. 55%, phase 2: 44% vs. 56%) of the study. Predominant medical disciplines were cardiology and pneumology. The majority of surgical patients underwent cardiac, thoracic or neurosurgery.

Characteristics regarding the stay in the WEA are summarized in Table 2. Most predominantly, SAPS-II and SOFA at the time of WEA admission were still high in both groups revealing the severity of illness in this patient group with prolonged weaning. Additionally, significantly higher values could be detected in group 2 for SAPS-II. The total LOS in ICU and in WEA was significantly longer in patient group 1 without protocolized, systematic physiotherapy. Lastly, while patients from group 1 appeared to have a longer duration on RRT in the weaning unit, this was not statistically significant.

The study's primary endpoint, the objectified muscle strength measured by the Surgical Intensive Care Unit Optimal Mobilization Score (SOMS) and the handgrip test, are given in Table 3. Significant improvement could be demonstrated within group 2 after a protocolized, systematic physiotherapy.

Despite significantly longer MV duration in group 1 (see Table 2), there were no detectable differences between groups (see Fig. 2) with respect to the secondary endpoint, weaning success rates, Ventilator-free days were also comparable between groups (4.1 ± 5.1 in group 1 vs 3.1 ± 4.1 days in group 2, $p = 0.2971$).

Table 1
Demographic and clinical characteristics of prolonged weaning patients without (group 1) and with (group 2) protocolized, systematic physiotherapy.

Characteristic	Phase 1 (group1)	Phase 2 (group2)	*p*-value
	(*n* = 53)	(*n* = 53)	
Sex, n (%)			0.4120[a]
male	33 (62.3)	37 (68.8)	
female	20 (37.7)	16 (30.2)	
Age, years	67.4 ± 8.5	64.1 ± 12.4	0.1129[b]
Pre-existing diseases, n (%)			0.8770[c]
CAD	23 (43.4)	20 (37.7)	
COPD	14 (26.4)	15 (28.3)	
Asthma bronchiale	0 (0)	1 (1.9)	
Neuromuscular diseases	3 (5.7)	2 (3.8)	
Pre-existing COPD and GOLD-stages, n (%)	14 (26.4)	15 (28.3)	0.7233[c]
unknown	5 (35.7)	6 (40)	
GOLD I-III	6 (42.9)	4 (26.7)	
GOLD IV	3 (21.4)	5 (33.3)	
SAPS-II at ICU admission	35.8 ± 9.6	37.9 ± 11.2	0.3310[b]
SOFA at ICU admission	9.6 ± 3.2	9.4 ± 2.9	0.7539[b]
RRT during ICU stay, n (%)	13 (24.5)	20 (37.7)	0.1584[c]
Length of RRT in ICU, days	11.8 ± 8.9	8.3 ± 4.1	0.2046[a]
Total ICU LOS, days	16.5 ± 15.1	14.9 ± 10.0	0.5306[a]

CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; GOLD, Global Initiative for Chronic Obstructive Lung Disease; SAPS, II Simplified Acute Physiology Score II; SOFA, sequential organ failure assessment score; RRT, renal replacement therapy; ICU, intensive care unit; LOS length of stay.
[a] Chi^2-Test.
[b] Satterthwaite's *t*-test.
[c] Fisher's exact test.

Table 2
Clinical characteristics at the time on the weaning unit (WEA).

Characteristic	Phase 1 (group1)	Phase 2 (group2)	p-value
	(*n* = 53)	(*n* = 53)	
Total LOS (ICU & WEA), days	62.2 ± 29.5	47.6 ± 28.5	0.0111[a]
LOS in WEA, days	31.9 ± 22.2	21.6 ± 15.3	0.0061[a]
SAPS-II at WEA admission	32.0 ± 7.5	36.4 ± 10.3	0.0119[b]
SOFA at WEA admission	7.1 ± 2.3	7.1 ± 2.2	0.8633[b]
Vasopressor therapy in WEA, n (%)			0.2242[c]
none	21 (39.6)	27 (50.9)	
minimale dosage (0–0.2 μg/kg/min)	22 (41.5)	22 (41.5)	
moderate dosage (0.2–0.5 μg/kg/min)	7 (13.2)	4 (7.6)	
high dosage (> 0.5 μg/kg/min)	3 (5.7)	0 (0)	
RRT during WEA stay, n (%)	5 (9.4)	9 (16.9)	0.2512[a]
Length of RRT in WEA, days	13 ± 13.9	4.7 ± 5.9	0.2139[b]
Length of MV (ICU & WEA), days	40.4 ± 24.3	31.3 ± 18.2	0.0321[b]

LOS, length of stay; ICU, intensive care unit; WEA, weaning unit; SAPS, II Simplified Acute Physiology Score II; SOFA, sequential organ failure assessment score; RRT, renal replacement therapy; MV, mechanical ventilation.
[a] Chi^2-Test.
[b] Satterthwaite's *t*-test.
[c] Fisher's exact test.

Table 3
Primary endpoints of the study.

Characteristic	Phase 1 (group1)	Phase 2 (group2)	p-value
	(*n* = 53)	(*n* = 53)	
SOMS			
0 = no activity			
1 = passive, bed rest			
2 = sitting			
3 = standing			
4 = walking mobility			
Value of improvement on mobility*	1.02 ± 1.07	1.7 ± 1.05	0.0073[a]
Pts without improvement, n (%)	20 (37.7)	9 (16.9)	0.0165[b]
Handgrip test			
Maximum value left hand, kg	12.8 ± 9.5	17.5 ± 10.1	0.0294[a]
Maximum value right hand, kg	13.6 ± 10.9	17.5 ± 9.9	0.0792[a]
Pts without improvement right hand, n (%)	13 (27.7)	3 (6.8)	0.0091[b]
Pts without improvement left hand, n (%)	15 (31.9)	0 (0)	<0.0001[b]

SOMS, Surgical Intensive Care Unit Optimal Mobilization Score.
[a] Doubled *t*-Test.
[b] Chi^2-Test.
[*] Given as the mean difference between min and max values.

Regarding mortality, the number of patients who died in the WEA was significantly higher within group 1 (see Table 4). Furthermore, the prevalence of infectious complications during treatment on the WEA was also significantly higher in group 1. There appeared to be a clear trend towards higher rates of delirium in group 1. However, it was not statistically significant. (see Table 4).

Multivariate logistic regression analysis with selection of risk factors resulted in seven relevant variables. Neither infections nor ICUAW had a relevant impact on mortality in our cohort and thus were removed early during the elimination process. The respective variables, the ORs and 95% CIs are given in Table 5. Protocolized, systematic physiotherapy resulted in a significantly higher probability of survival.

4. Discussion

In this observational study, it was found that a protocolized,

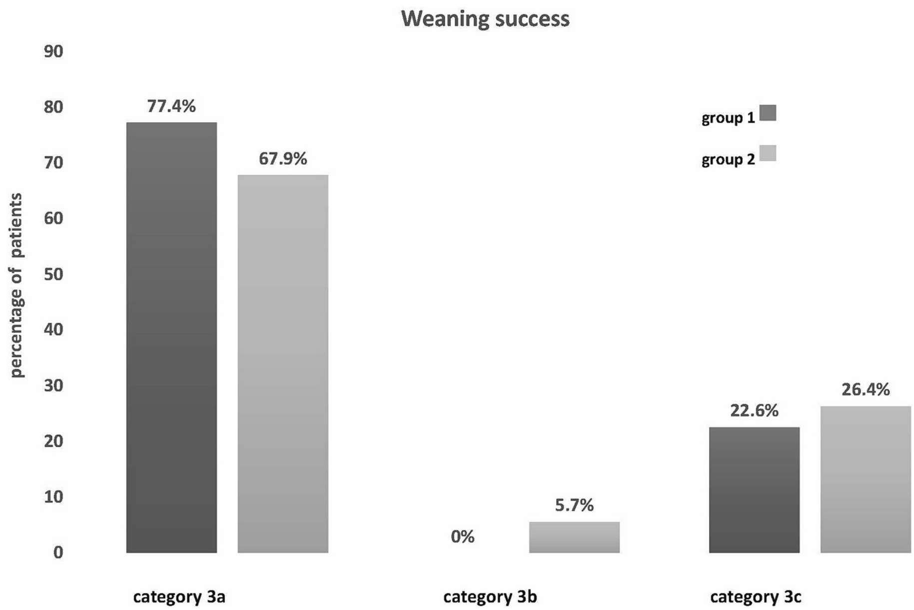

Fig. 2. Weaning categories at the time of WEA discharge.
Category 3a: successful weaning after at least three failed SBT or MV longer than 7 days after the first failed SBT without the use of NIV; 3b: successful weaning after at least three failed SBT or MV longer than 7 days after the first failed SBT in combination with NIV; if necessary, continued into out-of-hospital (home) MV; 3c: weaning failure: indication for permanent, invasive home ventilation or death during the process of prolonged weaning.

Table 4
Relevant secondary endpoints of the study.

Characteristic	Phase 1 (group1)	Phase 2 (group2)	p-value
	($n = 53$)	($n = 53$)	
WEA mortality, n (%)	8 (15.1)	2 (3.8)	0.0462[a]
Pneumonia /pneumonic sepsis, n (%)	41 (77.4)	17 (13.2)	< 0.0001[a]
Urosepsis, n (%)	22 (41.5)	6 (11.3)	< 0.0001[a]
Delirium, n (%)	33 (62.3)	23 (43.4)	0.0517
ICU-acquired weakness, n (%)	22 (41.5)	14 (26.4)	0.1008

[a] Chi^2-Test.

Table 5
Multivariate regression analysis, dependent variable: mortality.

Variable	OR	95% CI		p-value
Male sex	2.954	0.610	14.300	0.1784
CAD	0.266	0.056	1.267	0.0962
Sum SAPS II TISS-10 on WEA	1.062	0.977	1.154	0.1560
Vasopressor therapy in WEA, minimal dosage	1.477	0.306	7.121	0.6269
Vasopressor therapy in WEA, moderate dosage	18.508	2.422	141.461	0.0049
Vasopressor therapy in WEA, high dosage	35.856	1.618	794.535	0.0235
Protocolized, systematic physiotherapy	0.151	0.031	0.745	0.0203

systematic physiotherapy approach could be objectively measured by the SOMS and the handgrip test.

The total length of ICU (and weaning unit) treatment as well as the time on MV was shortened. Furthermore, the implementation resulted in a reduced number of infections and a lower mortality rate.

Interestingly, although the clinical problem (and its corresponding pathomechanisms) of ICU-acquired, muscular weakness is quite evident in critically ill, mechanically ventilated patients, very few data exist on systematic physiotherapy approaches in patients with prolonged weaning. In a recently published meta-analysis, Lippi et al. (2022) revealed positive physiotherapy effects on MV time after different physical interventions, e.g., positioning, early mobilization or respiratory muscle training. They also bring up the issues of the large heterogeneity in patients, which limits comparability, as well as the lack of large clinical studies and unavailable data regarding the role of comprehensive physiotherapy interventions [16]. The authors concluded that further studies are needed to identify clear rehabilitation strategies to enhance the improvements in critically ill MV patients. Here, our study contributes to this challenge of defining clear physiotherapy strategies and systematic, structured approaches in the particular patient group of prolonged weaning. The need for such clear (and objectively measurable) strategies was also highlighted in a prospective observational study by Connolly et al. (2019). They included 42 long-term-treated ICU patients with invasive MV in the majority of cases (73.8% of cases with invasive MV) and recorded their physical activity profile. Among other methodologies, an Expanded ICU Mobility Scale and Intensity Classification was used for quantifying the physical activity of the patients. Strikingly, the patients spent 100% of the day located in bed with no or minimal activity for 99% of the day hours, regardless of their sedation status, and physiotherapy was initiated after eight days on average from ICU admission [17]. Their results of potentially poor physical activity behaviour across ICU patients again underline an urgent need for targeted strategies and the need for using tests to also assess the results beyond therapeutic rehabilitation.

In our study, two assessments were parallelly used, namely the handgrip strength and the SOMS. The latter is an especially proven, validated test in ICU patients [18]. A large international, multicenter study by Schaller and colleagues (2016) demonstrated the positive effects of early mobilization on ICU length of stay and the usefulness of an algorithmic management of the procedure by the SOMS among other measures. The analyzed patient group in this study consisted of surgical ICU patients. Patients in the intervention group reached higher levels of mobilization as indicated by higher SOMS levels. Early mobilization therapy was already initiated one day after study inclusion [19]. In contrast to our study, however, the patients had a much shorter ICU LOS.

The handgrip strength was one additional measurement in our study to objectively measure the increase in peripheral muscle activity. A validated and routinely used dynamometer was applied for quantification. Hand dynamometry is a reliable method for measuring muscle strength in cooperative critically ill patients and was previously described in ICU patients with MV. Cottereau et al. (2015) prospectively used the handgrip test closely before a first spontaneous breathing trial (SBT) was performed in 84 included subjects. Median time before first SBT was surprisingly six days, and they stated that the first handgrip test (performed before initiating a structured weaning process) was associated with difficult or prolonged weaning, but not with the outcome of extubation [20]. Thus, the handgrip test was used as a predictive tool in ICU patients with rather short MV duration. Other clinical studies trying to correlate peripheral muscle activity with ICU LOS and MV demonstrated the reliability of the test method [21,22]. However, in contrast to our study, these studies only described methods and did neither focus on patients with prolonged weaning nor consider possible effects of structured physiotherapy.

Besides a high incidence of ICUAW, patients with prolonged weaning from MV are characterized by fluid overload, malnutrition, secondary anemia, secondary infectious complications, endocrinological impairment, delirium, and further syndromes after acute ICU treatment. Next to co-morbidities, many causes of respiratory overload need to be overcome. This extensive, functional recovery, which is often performed in specialized weaning centres, requires multi-professional approaches with physicians, psychologists, speech therapists and physiotherapists. The working group of Clini et al. (2011) focused on the physical training in patients with difficult weaning being admitted to their weaning center. They could show that the weaning success was associated with an increase in Basic Activities of Daily Living (BADL) measured by the BADL score. Their approach of peripheral muscle training was started 48 h after admission. In contrast to our data, their patients had a comparably shorter ICU stay (minimum of 14 consecutive days in ICU) before being transferred to the weaning unit and were most predominantly medical patients [23]. All in all, data on a structured inclusion of physiotherapy in patients with prolonged weaning is still scarce.

In our study, we focused on patients in prolonged weaning admitted to a specialized weaning unit. These patients suffered from the most severe form of respiratory insufficiency and showed several characteristics that may separate them from other ICU patients [24]. Their high SOFA and SAPSII-scores at the time of WEA admission clearly demonstrated a certain severity of illness, making the data comparable to a previous study on prolonged weaning patients [25]. Schreiber et al. 2019 could also demonstrate a useful effect of physiotherapy on patients requiring prolonged MV, but did not apply objective measurements for analysis. The evidence on the effect of structured physiotherapy of critically ill patients on physical function or performance, and the incidence (and regredience) of ICUAW is still insufficient and it is known that a multifactorial, concise management (e.g., time management, weaning protocols, analgosedation protocols, early recognition of secondary complications, fluid management, etc.) is needed to improve the outcome in this particular patient group [26]. Given this known clinical situation, the many possible confounding factors make it difficult to directly draw conclusions regarding the role of physiotherapy in weaning success or failure.

The data from this study contributes to this field by providing evidence that protocolized, systematic physiotherapy shortens MV, ICU- and weaning LOS, decreases infectious complications and might improve survival. The difference of mortality rates must be seen with caution due to the low number of patients.

The non-significant differences of the weaning success in our patients of prolonged weaning, presented as the number of patients within category “3a” (successfully weaned from MV without additional respiratory support), can be possibly explainable by the fact that the rates were only documented at the time of WEA discharge. The longer days on MV in group 1 could better characterize or show the possible effect of physiotherapy on weaning progress. Thus, time until classification/categorization would be reached faster, leading to an obviously better and optimalized use of resources and capacities.

Beside the positive effect of protocolized, systematic physiotherapy in the multivariate regression analysis, it was demonstrated that increasing dosages of vasopressors increase the probality of dying.

It should be noted that our study has limitations. To begin with, it was conducted as an observational study as opposed to a randomized, controlled trial, which would be a more powerful design to further assess the effects of protocolized, systematic physiotherapy. The effects of usage of protocols goes along with longer operating times of personnel. Thus it cannot be excluded that this might have been a bias leading to clinical improvement per se or whether it was an effect of the protocolized approach alone. However that increasing personnel hours alone – without protocols – might not result in such effects.

Futhermore, our retrospective analysis and respective data originate from only one single center. The observational character of our study is a major drawback of this analysis, since it is not intended to prove that a certain influencing factor is responsible for a certain outcome. Instead, it is only capable of showing correlations without the knowledge about causality. Nevertheless, we consider the results of the retrospective evaluation to be so relevant that they would like to motivate further, also prospective, work in this field by publishing the results.

Additionally, we analyzed endpoints regarding treatment while on the weaning unit, but cannot provide any data on long-term outcomes in our patients. Given these considerations, extrapolation of these results to a more general setting should be done with caution.

5. Conclusion

The results of our analysis provides evidence towards the urgent need for physiotherapeutic action in patients undergoing prolonged MV and prolonged weaning. However, there is still insufficient evidence on the effect of structured physiotherapy of critically ill people in the ICU (or specialized weaning units) on physical function or performance, adverse events, ICUAW and recurring muscle strength at this time. These results may deliver one module on improving patient-related outcomes, which is namely the awareness of using objectively measurable attributes for assessing physiotherapy success.

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CRediT authorship contribution statement

Johannes Bickenbach: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Sebastian Fritsch:** Data curation, Methodology, Writing – review & editing. **Sophia Cosler:** Methodology, Project administration. **Yvonne Simon:** Investigation. **Michael Dreher:** Writing – review & editing. **Silke Theisen:** Project administration. **Joyce Kao:** Writing – review & editing. **Frank Hildebrand:** Writing – review & editing. **Gernot Marx:** Writing – review & editing. **Tim Philipp Simon:** Conceptualization, Methodology, Project administration.

Declaration of Competing Interest

The Authors declare that there is no conflict of interest.

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