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Review Paper

Inspiratory muscle training for intensive care patients: A multidisciplinary practical guide for clinicians

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ABSTRACT

Objectives: To describe a multidisciplinary approach to inspiratory muscle training (IMT) for patients in the intensive care unit (ICU).
Background: Inspiratory muscle weakness is a known consequence of prolonged mechanical ventilation, and there is emerging evidence that specific IMT can ameliorate this weakness. However, IMT is not yet standard practice in many ICUs, possibly because of the wide variety of methods reported and a lack of published practical guidelines. While the optimal parameters for IMT are yet to be established, we share our detailed methodology which has been shown to be safe in selected ventilator-dependent patients and is the only approach which has been shown to increase quality of life in ICU patients.
Methods: Patients who have experienced invasive mechanical ventilation for at least 7 days can commence IMT in either the ventilator-dependent phase or when weaned from mechanical ventilation. Intensity should be prescribed based on maximum inspiratory pressure, which is measurable through the tracheostomy or endotracheal tube via the ventilator or a respiratory pressure meter. Using a removable threshold device, we recommend high-intensity training (5 sets of 6 breaths at a minimum of 50% of maximum inspiratory pressure) performed once per day, supervised by the physiotherapist, with intensity increased daily such that patients can only just complete the 6th breath in each set.
Results: Using this high-intensity approach, IMT is likely to improve not only inspiratory muscle strength but also quality of life in patients recently weaned from mechanical ventilation of 7 days' duration or longer. Effective IMT requires a multidisciplinary approach to maximise feasibility, with doctors, nurses, and therapists working closely to optimise conditions for successful IMT.
Conclusions: This multidisciplinary approach to implement IMT in ICU patients should assist clinicians in translating best-available evidence into practice, with the potential to enhance patient recovery.

1. Introduction

Invasive mechanical ventilation (MV) is an essential and life-saving intervention in the intensive care unit (ICU); however, prolonged MV often leads to impaired inspiratory muscle strength

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and endurance.[1–5] Diaphragmatic atrophy occurs rapidly and is detectable in patients after just 18–69 h of controlled MV.[6] In patients mechanically ventilated for more than 24 h, diaphragmatic dysfunction is associated with difficult and prolonged weaning.[3,5] In a study of 124 patients ventilated for more than 24 h, 54% had detectable inspiratory muscle weakness before ventilatory weaning, and inspiratory muscle weakness was independently associated with 1-year mortality.[7] Diaphragmatic atrophy tends to be worse in patients ventilated with controlled modes compared to spontaneous modes and appears to be related to a patient's inspiratory effort whilst ventilator-dependent.[8] While many Australian ICUs preferentially use more spontaneous modes of ventilation (i.e. pressure support), impaired inspiratory muscle strength remains a persistent problem in a third of patients largely ventilated through spontaneous modes.[1] Furthermore, inspiratory muscle weakness is likely to contribute to the elevated dyspnoea observed in one-third of patients recently weaned from prolonged MV.[1] Thus inspiratory muscle impairment may negatively affect recovery for many ICU patients.

Over the past 15 years, inspiratory muscle training (IMT) (i.e. specific strengthening of the inspiratory muscles) has emerged as a promising treatment for ICU patients. A recent systematic review[9] of 28 studies (n = 1184) revealed that IMT improves inspiratory muscle strength in ICU patients and is associated with acceleration of ventilatory weaning. Furthermore, in patients who have failed to wean from MV, IMT may enhance weaning success.[10] Improvements in inspiratory muscle strength, as a result of IMT, have also been associated with improvements in quality of life following just 2 weeks of training in patients recently weaned from MV.[11] Given the reversibility of inspiratory muscle weakness and the potential benefits to patients' quality of life, ICU clinicians are now seeking to translate this evidence into practice.

Despite this emerging evidence, IMT is not standard practice in most ICUs around the world, as reflected in a recent survey of French physiotherapists.[12] The challenges of implementing IMT in ICU include the wide variety of training methods reported in the literature[9,12] and a lack of published guidelines regarding implementation in a real-world context. This article aims to describe a practical multidisciplinary approach to IMT in ICU, drawing on the available evidence and more than 10 years' clinical experience with IMT in both ventilator-dependent and recently weaned patients. It is hoped that a detailed description of this approach, which requires medical, nursing, and physiotherapy input, will prove useful to clinicians seeking to implement IMT in their own ICU.

2. Inspiratory muscle training methods

2.1. General principles of IMT in ICU patients

Inspiratory muscle training is a targeted strengthening of the inspiratory muscles through the application of resistance during inspiration. A recent systematic review[9] has shown that IMT in ICU patients has been conducted using whole-body training, resistive loading, or threshold loading. There are no studies that have compared these approaches directly. An important difference between resistive and threshold loading is that resistive loading depends on the flow generated by the patient, making training intensity variable, depending on effort. In contrast, with threshold loading, patients must generate a preset pressure to allow airflow for each breath, and once that threshold is achieved, inspiratory flow is not dependent on patient effort. This means that threshold loading is the easiest of these IMT methods to standardise and prescribe for ICU patients.

The greatest benefits of IMT in ICU patients have been observed in studies which use a threshold device to provide the loading stimulus[9,10,13,14] (Fig. 1), as opposed to ventilator manipulations to provide resistance.[15] Through the spring-loaded threshold mechanism, the prescribing clinician can be sure of the reproducibility of the patient's efforts, facilitating accurate titration of IMT pressures to achieve a strengthening benefit.[9]

Training regimes for IMT vary widely across different patient populations (e.g. patients with chronic obstructive pulmonary disease and[16] chronic heart failure[17]) and athletes[18,19], including both high-intensity interval training[10] and endurance-focused training (e.g. breathing against lower resistance for 20–30 min[17]). Many ICU patients are not capable of maintaining resisted inspiration over several minutes, as described in IMT protocols for other patient groups,[16,17] and in our experience, the high-intensity interval approach[10,11,13,14] is ideal. This approach uses few repetitions at the highest manageable resistance to briefly load the inspiratory muscles, while also allowing rests and recovery between sets to maximise tolerability. Of all the approaches described in the recent systematic review[9] of IMT in ICU patients, our approach uses the highest intensity (i.e. minimum of 50% of maximum inspiratory pressure), and this is safe and well-tolerated in carefully selected ICU patients.

Inspiratory muscle training can be performed in both ventilator-dependent and independently breathing ICU patients and ideally is conducted with the patient in an upright sitting position. As the technicalities of application differ between these two groups, they will be described separately.

2.2. Ventilator-dependent patients

2.2.1. Patient selection

There are several factors to consider in determining whether IMT is appropriate for an ICU patient, and these factors are summarised in Fig. 2.

As patients need to actively participate in IMT, alertness and cooperation are essential. Patients need to be awake enough to comprehend the purpose of the intermittent loading so that they perceive it as a temporary training stimulus, as opposed to a sign of deterioration or a source of distress. Thus, minimisation of sedation is a crucial component of the multidisciplinary approach to IMT in ICU, and based on our experience,[11,20,21] alertness should be titrated to a Riker Sedation Agitation Score[22] of 4 (or equivalent).

Artificial airways do not preclude IMT as training is feasible and safe in selected patients with either an endotracheal tube (ETT) or tracheostomy *in situ*. As threshold-based IMT necessitates

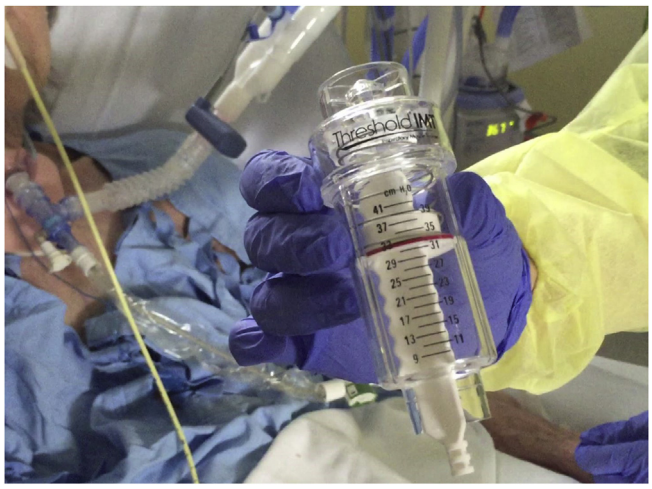

Fig. 1. Spring-loaded inspiratory muscle training device.

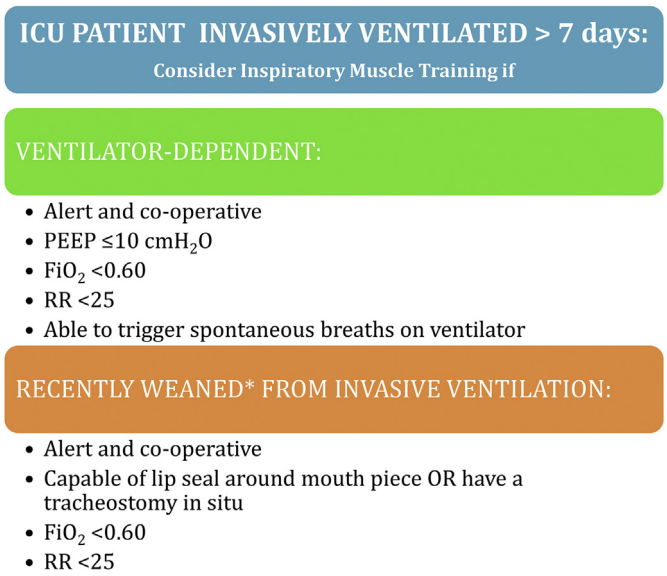

Fig. 2. Patient selection for inspiratory muscle training in ICU. ICU = intensive care unit; PEEP = positive end expiratory pressure; FiO_2 = fraction of inspired oxygen; RR = respiratory rate. * Recently weaned means independently breathing for 24 h per day without any invasive ventilatory support.

disconnection from MV, patients must not be dependent on high levels of positive end expiratory pressure (PEEP) as disconnection is highly likely to result in de-recruitment and atelectasis. However, for medically stable patients with PEEP levels $\leq$10 cmH_2O and a fraction of inspired oxygen <0.60, our approach to IMT does not result in clinically or statistically significant changes in oxygen saturation or respiratory rate,[20] suggesting that atelectasis is unlikely in this group of patients. Owing to other risks of disconnection, IMT is not feasible for patients undergoing nitric oxide therapy, nebulised prostacyclin, or high frequency oscillation. However, in our experience, IMT is safe with patients admitted with a primary diagnosis of chronic obstructive pulmonary disease (COPD) (including those with a degree of auto-PEEP), as long as they also satisfy the criteria described in Fig. 2.

The patient's baseline respiratory rate should be stable at less than 25 breaths per minute, as we have found that patients will struggle to maintain a respiratory rate faster than this during loaded breathing (where the inspiratory valve is open for at least 1 s[21,23]). Haemodynamic parameters should also be stable, as IMT could theoretically cause transient changes to intrathoracic pressure which may affect venous return, although there are no data to directly support the clinical impact of this risk. In patients with stable blood pressure and heart rate, IMT does not cause statistically or clinically significant changes in either parameters.[20]

In terms of success with weaning from MV, patients most likely to benefit from IMT are those who have failed to wean via usual methods such as progressively longer t-piece trials over a period of days or weeks.[10,24,25] Although inspiratory muscle weakness may be evident as early as 24–48 h following commencement of MV,[5,6] very early IMT (i.e. from 48 h) has only shown minimal benefit in terms of weaning success, despite modest improvements in inspiratory muscle strength.[13,14] Clearly some patients will wean successfully from MV without any need for IMT. However, many ICU patients who successfully wean from MV of $\geq$7 days have ongoing deficits in inspiratory muscle strength and endurance[1,2] which can manifest as elevated dyspnoea both at rest and during exercise.[1] From this perspective, our practice is to consider IMT for any ICU patient from Day 7 of MV, with reassessment every day thereafter if not initially suitable.

There are several conditions where IMT would not be appropriate for ICU patients, for example, in those who are acutely deteriorating, experiencing severe pain or dyspnoea, or who have shifted to a palliative treatment approach.[26] As studies of IMT to date have not included pregnant women, it is not possible to comment on the suitability of IMT for this subgroup of ICU patients, and the appropriateness of IMT would need to be discussed by the multidisciplinary team in terms of potential benefits and risks for the individual patient and fetus.

2.2.2. Equipment

A commercially available spring-loaded threshold IMT device can usually provide an appropriate training resistance for ICU patients, ranging between 9 and 41 cmH_2O (Fig. 1). This IMT device can be connected to an ETT or tracheostomy via a flexible or rigid connector, either directly or via an inline suction circuit (Fig. 3). For patients with an elevated sputum load, it is advisable to maintain the suction circuit *in situ*, as suctioning may be required between IMT sets due to rapid pressure changes and sputum dislodgement.

The spring-based simple IMT device is single-patient use and does not require maintenance and specific cleaning beyond rinsing and air-drying the mouthpiece. In our experience, the only risk to device integrity is that if the intensity is inadvertently dialled above 41 cmH_2O, the spring is liable to break, and the whole device will need to be replaced.

If available, a respiratory pressure meter can be used to determine the patient's baseline maximal inspiratory pressure (MIP). Using a flexible connector, the device can be attached directly to the ETT or tracheostomy (Fig. 4), and the patient can inhale maximally from residual volume. The instruction “empty your lungs” may be helpful in achieving an accurate measurement, ensuring the device is attached to the ETT or tracheostomy just after the lungs have been “emptied”. The patient should be coached to inhale as forcefully as possible, and in line with established best practice, this MIP measurement should be repeated three times to ensure consistency.[27] In ICU patients, MIP measurement may be a fatiguing process, and several minutes' rest on MV may be required between attempts.

If a respiratory pressure meter is not available, another option is to measure the “negative inspiratory force” (NIF) through the ventilator settings menu (often available under “special procedures” or “lung mechanics”) (Fig. 5). Similarly, this measurement should be from as close to residual volume as possible, but note that this will not be truly possible for patients with PEEP >0 cmH_2O. Nonetheless, if the patient can produce their maximal effort, the

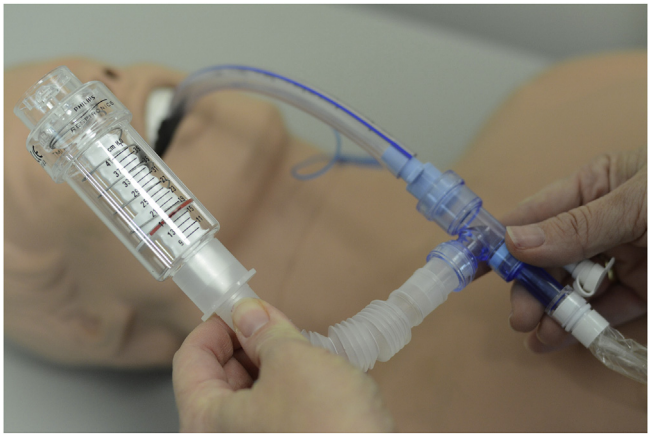

Fig. 3. IMT device connected to endotracheal tube with inline suction *in situ*. IMT = inspiratory muscle training.

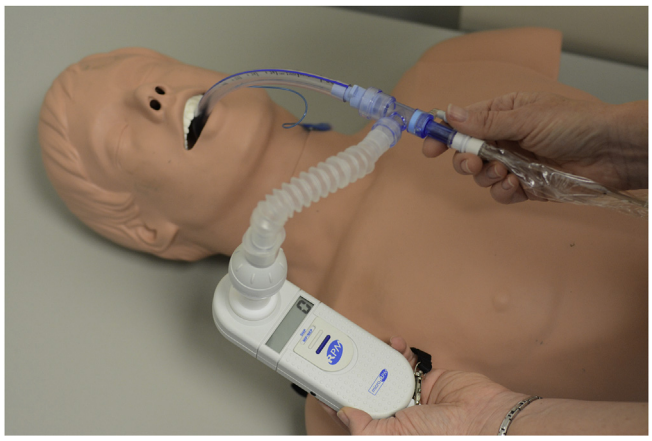

Fig. 4. Respiratory pressure meter connected to endotracheal tube via connector tube.

NIF score may provide a reproducible surrogate value of inspiratory muscle strength which will be useful in titrating IMT intensity.

2.2.3. Training parameters/prescription

As ICU patients often have very weak inspiratory muscles (e.g. MIP of approximately 30–35 cm H_2O when ventilated 7 days or longer[1,3]), it is unlikely that they will tolerate sustained loading of the respiratory muscles without distressing fatigue. To maximise benefits and minimise distress, a high-intensity low-repetition approach has been used successfully in numerous trials.[10,13,14] An intensity of at least 50% of MIP is well-tolerated, although in practice this should be considered the minimum training threshold, with intensity titrated upwards to the highest tolerated level where the patient can just complete the 6th breath in a set of six breaths.[10,26]

Given this high level of intensity, only few repetitions are required, and a set of six breaths is achievable. A total package of five sets of six breaths daily (with rest days on weekends) is well-tolerated, and in carefully selected patients, it is unlikely to result in any short-term deterioration in oxygen saturation, respiratory rate, heart rate, or blood pressure, even without supplemental oxygen during training. It is important that the clinician supervising IMT returns the patient to normal ventilatory support between sets and allows adequate rest and recovery before attempting the next set. In our experience, most patients only require 1–2 min; however, this rest period may be longer in very weak or highly anxious patients.

If baseline MIP (or NIF) is not readily available, it is still possible to titrate IMT intensity via a trial-and-error method, commencing at a relatively low intensity (e.g. 9–15 cm H_2O) and gradually increasing intensity until the patient can just complete the 6th breath in each set. In this case, the first IMT session is likely to expend all the patient's energy in establishing the correct intensity, and training on the subsequent day should commence at the pre-established intensity.

As the patient's strength improves over time, the intensity should be increased incrementally to continue to provide the maximum tolerable training load. In our experience, this is typically in the magnitude of 1–2 cmH_2O every 1–2 days. Thus if a patient commences IMT at 15 cmH_2O, they may be training at 25 cmH_2O within 1 week. If the patient experiences a complication such as ventilator-associated pneumonia, where lung function is compromised by sputum load, it may be necessary to reduce the intensity or cease training for a few days and re-establish the appropriate

Fig. 5. Negative inspiratory force (NIF) measurement through the ventilator.

threshold for training once the complication has resolved and the eligibility criteria are met again.

2.2.4. Trouble-shooting

Not surprisingly, IMT may be particularly challenging for extremely weak patients, particularly those whose MIP is less than 18 cmH_2O. For these patients, commercially available threshold devices can be difficult if not impossible to use, as they are incapable of generating the pressure required to open the valve at the lowest setting for six breaths. For these patients, we have had some success with commencing with a sham IMT device of sorts, where they breathe for six breaths through just the flexible connector tube attached to their ETT or tracheostomy, providing only the slightest resistance. Once patients can manage five sets of six breaths at this level for several days, we can commence with just a few breaths at the lowest setting on the IMT device (i.e. 9 cmH_2O) and gradually build up to a full 6-breath set.

Timing of IMT is crucial with respect to ventilatory weaning. For patients undergoing spontaneous breathing trials (SBT), we have found that IMT is best scheduled either during the ventilator-dependent period, or at the end of the SBT, such that the patient can return to the ventilator for a complete rest at the end of the 5th set. It is essential that if the patient is breathing with a deflated tracheostomy cuff during the SBT, this cuff is reinflated during IMT to avoid air leaks and ensure accurate training intensity. Furthermore, if the tracheostomised patient is using a speaking valve during their SBT, this valve must be removed, and the tracheostomy inner cannula must be changed to a non-fenestrated tube, and the tracheostomy tube cuff must be reinflated, otherwise there will be excessive air leak around the tracheostomy tube and training pressures will not be reliably achieved. Clearly, close collaboration between the clinician supervising IMT and the bedside nurse in ICU is essential.

Another challenge of introducing IMT concerns the timing of other rehabilitation interventions. If patients are also completing whole-body exercise activities, we suggest scheduling IMT earlier in the day, allowing a rest period before the next exercise session. If patients are exhausted by whole-body exercise, they are unlikely to have the stamina and concentration required for optimal high-intensity IMT.

Very occasionally, for patients breathing through a humidified ventilator circuit, the valve in the IMT device can become waterlogged and stuck within the chamber. If this is the case, the device should be replaced as it will not be providing the preset threshold pressure expected.

In accordance with previous recommendations regarding safety of physiotherapy interventions in ICU,[28] IMT should be ceased should any of the following occur: alteration in blood pressure > or < or >20% resting, new arrhythmia, oxygen desaturation >10%, pulmonary artery pressure (systolic) >60 mmHg, suspected pneumothorax, and agitation risking detachment of equipment or lines or requiring increased sedation.[26] However, observational data have demonstrated that these events are extremely unlikely in ICU patients who meet the eligibility criteria described in Fig. 2.[20]

2.3. Independently breathing patients

2.3.1. Patient selection

Patients who have weaned from MV and are breathing independently may have commenced IMT while still ventilator-dependent or may have been unable to participate during MV. In some studies, more than 80% of ventilator-dependent patients cannot participate in IMT for various reasons, most commonly because of low levels of consciousness or delirium.[11,26] Nonetheless, many patients who have successfully weaned from MV typically have residual inspiratory muscle weakness, which may manifest as dyspnoea at rest or during exercise.[1] This is particularly the case for patients who have experienced MV for 7 days or longer, where both inspiratory and limb weakness are known to coexist.[1,3,5] A recent trial demonstrated that in patients who had recently weaned from MV, just 2 weeks of daily IMT improved not only inspiratory muscle strength but also quality of life.[11] Thus patients who have recently weaned from MV of 7 days or more are ideal candidates for IMT.

As for ventilator-dependent patients, independently breathing patients need to be alert and able to participate during IMT and should be medically stable without excessive pain or dyspnoea interfering with their breathing capacity. Owing to the use of a mouthpiece in the independently breathing population, patients also need to be able to maintain an adequate lip seal, and thus patients with bulbar dysfunction (e.g. due to stroke) or severe burns around the lips and mouth would not be appropriate for IMT (unless there is a tracheostomy *in situ*). Consistent with other guidelines, IMT in independently breathing patients is also not recommended for patients with high risk of pneumothorax or spontaneous rib fractures or within 12 months of lung surgery because of the high intrathoracic pressures generated during training.[16]

2.3.2. Equipment

In the independently breathing patient, the same commercially available IMT device described previously can be used; however, in this case, the mouthpiece and nose clip are essential (unless the patient is breathing through a tracheostomy).

A respiratory pressure meter can be used to determine the baseline MIP before commencing training, but rather than attaching the meter to an ETT or tracheostomy, the patient inhales through a disposable mouthpiece attached to the pressure meter. This MIP measurement should occur from as close to residual volume as possible and be repeated three times for reliability.[27]

2.3.3. Training parameters/prescription

Based on the randomised trial showing benefits for both strength and quality of life, patients should commence training at an intensity of at least 50% of MIP and complete five sets of six breaths daily (with rest days on weekends).[11] Patients should train at the highest tolerable intensity where they can just complete the 6th breath in each set. Where MIP measurement is unavailable, an appropriate IMT intensity can still be titrated from the patient's ability to perform six breaths in a row.

As strength improves, the intensity should be incrementally increased over days and weeks to ensure that training stimulus remains adequate. This is likely to be approximately 1–2 cm H_2O every few days, but may be faster in some patients. Training should continue for at least 2 weeks to achieve benefits in terms of quality of life.[11] While there is currently no evidence to guide training cessation in ICU patients, we suggest continuing until the patient achieves normal MIP scores for their age and gender [males = 120 − (0.41 × age); females = 108 − (0.61 × age)].[29] Extrapolating from evidence of IMT in patients with chronic lung disease, benefits are likely to be optimal with 6–8 weeks of training,[16] thus ongoing IMT may be beneficial well beyond the ICU admission.

2.3.4. Trouble-shooting

In patients who have weaned from MV and can continue training for several weeks, there is the risk of a ceiling effect as they may reach the training limit of the IMT device (i.e. 41 cmH_2O). However, this training intensity is equivalent to 50% of 82 cmH_2O, which would be within the normal predicted range for MIP in most patients.[29] In this situation, it is likely that the patient has returned

to their baseline inspiratory muscle strength. Nonetheless, electronic IMT devices could provide higher training pressures, and research is needed to determine whether there are any advantages to increasing inspiratory muscle strength further in ICU survivors.

2.4. Role of the medical team

The success of IMT in ICU patients is critically dependent on the engagement of the medical team. As patients need to actively participate, the medical team will need to minimise sedation which interferes with the patient's ability to comprehend and perform the training. The medical team may also be valuable in recognising a patient who is failing to wean from MV or who has recently weaned from prolonged MV and referring these patients to physiotherapy or respiratory therapy staff for IMT.

Furthermore, an appreciation of the nature of IMT as a potentially fatiguing stimulus will allow the medical team to prescribe ventilatory weaning plans which incorporate IMT at suitable time frames (e.g. towards the end of a SBT, rather than at the beginning). Clearly close collaboration between doctors and the rest of the multidisciplinary team is essential for the success of IMT in ICU patients.

2.5. Role of the ICU nurse

The beside nurse coordinates many therapies for the ICU patient, and the nurse's understanding of the value and importance of IMT will be critical to its success. The ICU nurse plays a pivotal role in optimising sedation levels to maximise alertness and facilitate IMT. Although an IMT treatment session only takes around 10–15 min, it should occur when a patient is well-positioned (i.e. high sitting), calm, and stable so that they can concentrate on training. Thus, the ICU nurse will need to liaise with the therapist as to the best time of day for IMT to occur, which may be after the patient has been hoisted into a chair or had a bed bath or procedure.

The ICU nurse may also directly assist with sputum clearance in ventilator-dependent patients before IMT, as sputum plugging is likely to interfere with training. For patients with a large sputum load, the ICU nurse may work closely with the therapist during IMT to provide suction as required, as the rapid changes in pressure may shift secretions unexpectedly. Furthermore, the nurse can anticipate the additional alarms that are likely to sound during IMT if the patient is being removed from the ventilator and reconnected repeatedly and work closely with the therapist to minimise the disruptive impact of these.

As the ICU nurse is largely responsible for the success of implementing a ventilatory weaning plan, their understanding of the role and effects of IMT is also crucial. As IMT is providing a high intensity stimulus, some patients may take several minutes to recover their stable breathing pattern following training.[13] In this context, ICU nurses are best placed to provide reassurance about the strengthening value of respiratory training, and this reassurance should reduce patient anxiety. The ICU nurse can also use their judgement about the need to return to ventilatory support should a patient's respiratory effort necessitate this. Thus, the ICU nurse and therapist work very closely to facilitate IMT in ICU patients, particularly with those who are ventilator-dependent.

2.6. Role of the physiotherapist or respiratory therapist

In studies of IMT which have demonstrated benefits in ICU patients, IMT has been performed directly under the supervision of a physiotherapist[11,13,14,21] or physical or respiratory therapist.[10,23,30] With a strong understanding of both respiratory pathophysiology and exercise training principles, these health professionals are well-skilled to initiate and progress IMT in ICU patients. Furthermore, as IMT may cause rapid changes in intrathoracic pressure and potentially shift sputum within the airways, these therapists are also skilled in monitoring and treating any side-effects of IMT as they arise. Therapists can also consider the timing of IMT in relation to other whole-body exercise interventions and ensure that fatiguing workloads are spread across the day for an ICU patient.

Although IMT will be initiated and performed by the physiotherapist or respiratory therapist, it is our experience that successful IMT requires a genuinely multidisciplinary approach. This is consistent with other rehabilitation interventions in ICU patients as described elsewhere.[31]

3. Discussion

This is the first practical guide for clinicians which specifically focuses on IMT in ICU patients. This guide is informed by evidence which has emerged over the past 15 years,[9] including randomised trials of IMT in both ventilator-dependent and independently breathing ICU patients. It is also underpinned by more than 10 years of experience with using IMT as a multidisciplinary team in a mixed ICU in a large teaching hospital,[1,11,21,32] and the importance of multidisciplinary collaboration in the success of this intervention cannot be emphasised enough.

A limitation of this guide is that the simple device suggested only provides training pressures from 9 to 41 cmH_2O. For some very weak patients, 9 cmH_2O will be unachievable, and although some alternative strategies have been suggested in this case, these problems may be overcome with electronic devices which can provide a much broader range of training pressures. These would also be advantageous for overcoming the ceiling effect of the simple device, as patients could also train at much higher pressures. While a single pilot study reports favourable outcomes in tracheostomised patients,[33] future studies should also explore the utility and feasibility of electronic IMT devices through ETTs and in ICU patients following successful ventilatory weaning, although the cost and infection control requirements of such devices would need to be considered.

Another limitation of this guide is that there is very little evidence to inform clinicians about the long-term effects of IMT in ICU patients. There is some evidence that long-term IMT can reduce the risk of hospitalisation in patients with chronic lung disease,[34] although the pattern of training employed in this study is very different from the high intensity interval training recommended for ICU patients. Future studies should explore whether IMT has any effects on hospital or ICU readmission rates and whether the quality of life benefits reported in the short term (i.e. within 2 weeks)[11] have any impact on outcomes beyond the hospital stay. Furthermore, the relationship between IMT and other rehabilitation strategies (e.g. early mobilisation) is not well-understood in ICU patients. This relationship deserves further investigation as the balance between specific and whole-body training might be important in optimising benefits or avoiding counterproductive training in the longer term.

Although all the evidence to date has examined the effect of supervised IMT in ICU patients, it is also possible that patients could benefit from continuing IMT independently following discharge from hospital, particularly if they are discharged before 6 weeks. Most IMT guidelines in other populations recommend at least 6–8 weeks of IMT to maximise benefits, with some recommending a maintenance program of two sessions per week for life to maintain benefits in the longer term (e.g. for patients with chronic obstructive pulmonary disease).[16] While future research should explore the feasibility of unsupervised IMT in ICU survivors, it seems

reasonable to encourage patients who have made good progress to continue their training beyond hospital discharge.

We have presented only one approach (high-intensity IMT using a threshold device), and the ideal training parameters for IMT are yet to be established. However, we have learned much from the evidence of IMT in patients with chronic lung disease, as well as endurance athletes, and the approach for ICU patients is informed by those principles (i.e. high-intensity interval training). It is hoped that this guide will assist ICU clinicians in translating the best-available evidence into practice by implementing IMT in their own ICUs, and if more clinicians are using a similar approach, this will enable future multicentre research to more robustly ascertain the impact of IMT on patient-centred outcomes, such as quality of life. In the short term, alongside other early and proactive rehabilitation strategies, IMT could be considered an important element of the rehabilitation toolkit to optimise recovery of critically ill patients.

4. Conclusions

Inspiratory muscle training is safe and feasible in selected ventilator-dependent ICU patients and those recently weaned from MV. Based on the available evidence, IMT is likely to enhance weaning and improve both inspiratory muscle strength and quality of life. The practical recommendations suggested in this guide should enable multidisciplinary ICU teams to offer IMT as an adjunct to rehabilitation for ICU patients, particularly those who experience MV for 7 days or longer.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.aucc.2018.06.001.

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