ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/391204667

Functional outcomes of inspiratory muscle training in elderly with intensive care unit-acquired weakness and severe walking disability

Article *in* Irish Journal of Medical Science · April 2025

DOI: 10.1007/s11845-025-03876-w

CITATIONS
7

READS
49

3 authors, including:

Hany Farid Elsisi
Cairo University
33 PUBLICATIONS **117** CITATIONS
SEE PROFILE

Ali Ismail
Cairo University
62 PUBLICATIONS **501** CITATIONS
SEE PROFILE

All content following this page was uploaded by Ali Ismail on 27 April 2025.

The user has requested enhancement of the downloaded file.

Irish Journal of Medical Science (1971 -) (2025) 194:761–769
https://doi.org/10.1007/s11845-025-03876-w

ORIGINAL ARTICLE

Functional outcomes of inspiratory muscle training in elderly with intensive care unit-acquired weakness and severe walking disability

Mushabbab Alahmari[1] · Hany Farid Elsisi[1] · Ali Mohamed Ali Ismail[2]

Received: 9 October 2024 / Accepted: 14 January 2025 / Published online: 3 February 2025
© The Author(s), under exclusive licence to Royal Academy of Medicine in Ireland 2025

Abstract

Background Intensive care unit acquired-weakness syndrome (ICUAWS) leaves several complications in functional movements of patients such as severe walking disability.

Objective Assessment of functional outcomes of 1-month inspiratory muscle training (IMT) in elderly with ICUAWS and severe walking disability was our aim.

The design, setting, participants, and intervention.

This study is a randomized controlled trial. ICUAWS patients who complained of severe walking disability on the Modified Functional Ambulatory Category Test (MFACT) were randomly assigned into the IMT group or control group, $n=20$ for each group. Both groups received the traditional physical therapy program.

Results The results showed that the post-therapy between-group comparison of ICUAWS sufferers/groups' parameters showed a significant improvement toward the IMT group in six-minute walk test, inspiratory and expiratory muscle strength, forced vital capacity, time up and go test, 10-m walk test, forced expiratory volume in the first second, 30-s sit-to-stand test, partial pressure of arterial blood oxygen and carbon dioxide, MFACT, oxygen saturation of arterial blood, physical, and mental summary of short form 36.

Conclusion In conclusion, IMT improves functional outcomes in ICUAWS patients with walking disability.

Trial registration number The clinical trial ID of this ICUAWS trial is NCT06210763.

Keywords Elderly · Exercise · Functional outcomes · Inspiratory muscle training · Intensive care unit acquired weakness · Walking

Introduction

In critically ill patients, the physicians' aim of medical/pharmacological treatment is directed mainly toward stabilizing the acute life-threatening disease/disorder. Anesthesia, repeated corticosteroid administration, mechanical ventilation, and/or sedatives/neuromuscular blockade are usually used as medical interventions in the intensive care unit (ICU) for sufferers with critical illnesses. Multiple scientific documentations are reporting that these interventions usually induce chronic systemic inflammation, massive catabolic processes, extended periods of immobility, and neurocognitive/neuromuscular insults/disorders including ICU-acquired-weakness syndrome (ICUAWS) [1].

The disorder that is induced by primary myopathy and/or axonal neuropathy in patients hospitalized in ICU due to the presence of critical illness is the definition of ICUAWS. As a complication of ICU stay, the prevalence of ICUAWS is 25–33%. The underlying mechanism of ICUAWS is not fully explained but cumulative microvascular/metabolic changes, electrical/bioenergetic alterations, muscular weakness, and muscular atrophy may be the cause of ICUAWS appearance. ICUAWS is a symmetrical neuromuscular disorder that affects mainly respiratory and proximal limb muscles while facial/ocular muscles are often spared [2].

✉ Ali Mohamed Ali Ismail
ali-mohamed@cu.edu.eg

[1] Department of Respiratory Therapy, College of Applied Medical Sciences, University of Bisha, Bisha, Saudi Arabia

[2] Department of Physical Therapy for Cardiovascular/Respiratory Disorder and Geriatrics, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

High morbidity is frequently reported in ICUAWS patients. Beyond the hospitalization period, recent documentations report ICUAWS-associated long-term post-intensive care syndrome (PICS, a syndrome of mental/cognitive and physical dysfunctions). PICS negatively impact daily activities, physical functions, walking, and quality of life among ICUAWS survivors [3].

ICUAWS-induced respiratory manifestations/complications are very common. These complications are rapid/shallow breathing, accumulated/sticky secretions in airways, increased use of accessory respiratory muscles, increased risk of atelectasis/aspiration, diaphragmatic weakness (suggested by during-inspiration paradoxical abdominal movement), during-talking dyspnea/breathlessness, and ineffective cough mechanism [4]. The ICUAWS-induced decrease/loss of respiratory muscular strength causes impairments in the execution of functional/physical activities (routine daily activities and walking) and high energy expenditure/loss during the performance of simple routine activities (dressing, eating, and bathing) [5].

Different pulmonary rehabilitation techniques (breathing exercises, aerobic training, active and resisted range of motion exercises of joints of upper and lower limbs, and nutritional/psychological counselling) documented improved respiratory muscle strength/endurance, enhanced ventilator function tests, decreased exercise intolerance, increased performance of physical activities, and improved quality of life. Inspiratory muscle training (IMT) devices are relatively new devices that are routinely used during pulmonary rehabilitation programs in patients with chronic respiratory disorders [6]. Breathing against within IMT device external load is the definition of an inspiratory muscle trainer device. There are great reported advantages of IMT devices. Improved exercise capacity/tolerance, diaphragmatic thickness/mobility, cardiovascular autonomic balance/control, quality of life, and walking abilities after rehabilitation programs in healthy, older, and ill subjects are some of IMT devices' reported advantages in literature [7].

The rehabilitation of walking/ambulation appears to be a great aim of rehabilitation programs for ICUAWS sufferers because walking is the main physical activity that is strongly needed to perform patients' basic daily activities and to prevent patient dependence and poor quality of life. To our knowledge, in the context/field of ICUAWS trials, no previous randomized-controlled rehabilitation trial has been discussed/investigated the 4-week effect of IMT on functional outcomes in patients with ICUAWS and severe walking disability, so this trail was built for this mentioned aim.

Methods

Design

A randomized-controlled post-acute ICU-discharge rehabilitation study.

Settings

The settings of this ICUAWS trial were in a local hospital (general hospital/facility). The rehabilitation of the ICUAWS participants was from 2 August 2023 to 30 March 2024 (clinical trial ID: NCT06210763).

Ethics

Helsinki rules for applying/performing clinical trials/research are considered. The unique code of local ethical Cairo-university approval was P.T.REC/012/004624.

Criteria of included ICUAWS patients

The included elderly were diagnosed as ICUAWS according to the presence of by-physician clinical interpretations of results of electrophysiological studies (nerve conduction studies and electromyography) and/or the presence of a total score of Medical Research Council (MRC) that defines ICUAWS was < 48. To be noted, MRC is a tool designed to assess bilateral strength of twelve muscle groups (wrist extensors, shoulder abductors, elbow flexors, knee extensors, dorsiflexors, and hip flexors) with a score appointed between zero (to muscle that did not contract at all) to five (to muscle that shows normal strength), while the total MRC score ranged from 0 to 60 [2]. The included patients were recently received mechanical ventilation weaning procedures and/or discharged from the ICU unit. The included ICUAWS sufferers complained of severe walking disability (i.e., having a score ≤ 4 on the modified functional ambulatory category test) and they had active preserved movement in muscles of the upper and lower limbs. The included patients were free from any neurological, orthopedic, or limb amputation problems.

Randomization

The included ICUAWS elderly ($n = 40$) were randomly and equally assigned into the IMT group ($n = 20$ ICUAWS patients who received IMT, routine chest physiotherapy, resisted upper and lower limb exercises, neuromuscular electrical stimulation) or control group ($n = 20$ ICUAWS patients who received the same intervention of the other

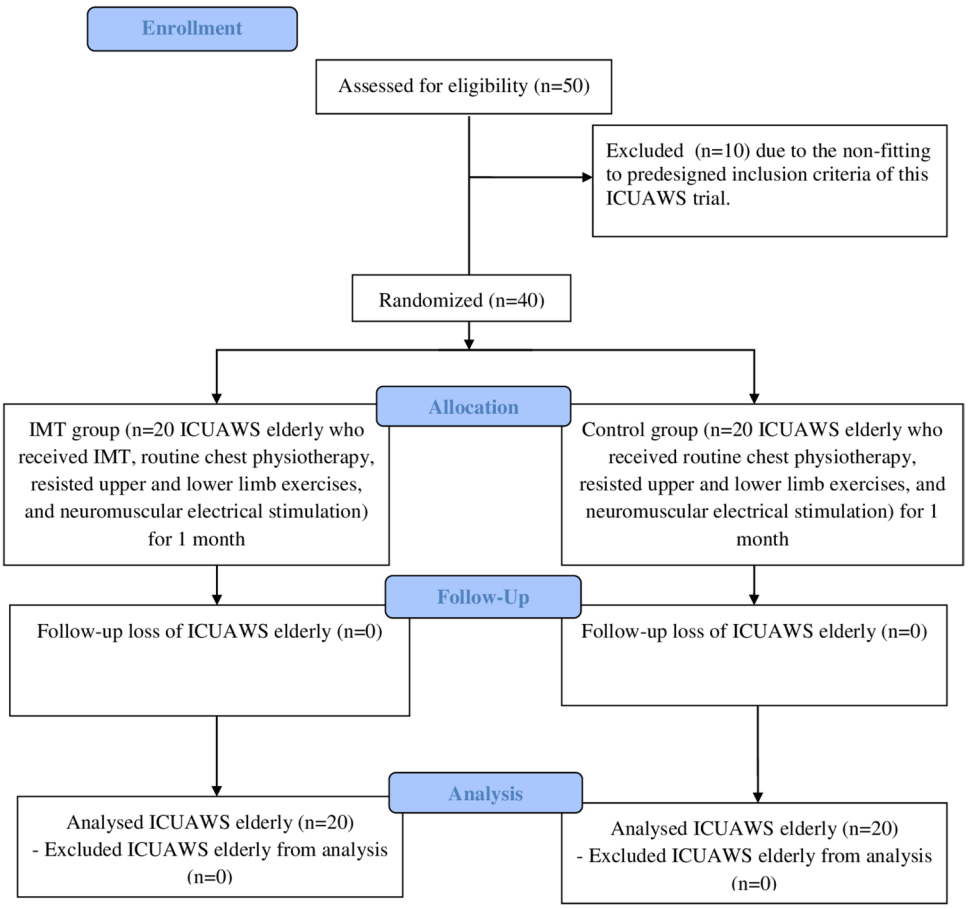

Fig. 1 Flow chart of ICUAWS elderly

group except IMT) (Fig. 1) (sessions were performed via a well-trained physical therapist with the assistance and the supervision of third author). A physical therapy assistant was displaced by authors from participation in this rehabilitation study performed the randomization which was done via the closed envelope technique.

Interventions

Upper limb resistance exercises (nearly 15 min)

Free weights (sandbags) were used for the exercises, and the resistance was set to 50% of the maximum load determined by the maximum repetition test. For the resistance training, three sets of 10 repetitions each of the right and left arm's flexion and abduction movements were done. The right elbow was flexed and extended, followed by the left elbow, in 3 sets of 10 repetitions. The right wrist was flexed and extended, followed by the left wrist, in three sets of ten repetitions. Depending on the patient's tolerance, there was a rest period of 1–2 min between each set of exercises [8].

Lower limb resistance exercises (nearly 15 min)

With the same idea of training upper limb muscles via resistance training, free weights (sandbags) were used for lower limb resistance exercises, and the resistance was set to 50% of the maximum load determined by the maximum repetition test. For the resistance training, 3 sets of 10 repetitions of each of the right and left hip flexion and abduction movements were done (right hip movements were done first followed by the movements of the left hip. The right knee was flexed and extended, followed by the left knee, in 3 sets of 10 repetitions. The right ankle was dorsiflexed, followed by the left ankle, in 3 sets of 10 repetitions. Depending on the patient's tolerance, there was a rest period of 1–2 min between each set of exercises.

Neuromuscular electrical stimulation

A 30-min neuromuscular electrical stimulation session was executed daily (5 days/week) on an upper limb (bilateral triceps and wrist extensor muscles) and lower limb (bilateral quadriceps and dorsiflexor muscles). The used intensity levels were directed to induce visible muscular contractions

which were tolerated by the ICUAWS patients. In case of doubt, local palpation confirmed the muscular contraction.

Chest physiotherapy

In patients with ICUAWS, nearly 15-min sessions of traditional chest physiotherapeutic treatment/preventive techniques cough training, vibration and/or shaking, therapeutic percussion, rib springing, and postural drainage positions (used in patients with retained secretions) were applied.

IMT protocol

In a comfortable sitting position on a chair, the ICUAWS-group patients who were trained via an IMT device (Philips Respironics threshold) were ordered to place the nose clip (delivered to them by the therapist) on their nose. The baseline maximum inspiratory pressure (MIP) of ICUAWS patients was measured to detect the IMT intensity. All ICUAWS patients were trained at the intensity of IMT equal to 40% of their basal MIP. After releasing full relaxed expiration, ICUAWS patients were ordered to put the IMT device's mouthpiece in their mouth during the inspiratory phase of respiration, while they were ordered to strongly and deeply inhale to release the IMT device's valve. For 4-week successive IMT sessions, three sets breathing training (the set contained ten breaths), separated by 1-minute rest [9], were executed two times daily. The IMT sessions were applied five times per week.

Outcomes of this ICUAWS trial

Primary outcome

The net score of the modified functional ambulatory category test (MFACT) was the primary outcome of this ICUAWS trial. The authors of this study utilized the seven-point Likert-scale (I to VII) walking/ambulation test, MFAC, to detect/evaluate gait variations/differences between the patients [10]. Gait/walking testing using MFAC was used to assess the following seven items [11]:

- *Item/grade I of MFACT*: the tested patient had could not perform the usual gait and needed external manual assistance/help to make a sitting position or the tested patient was unable to perform a 1-min sitting position without back and/or hand support with the bed/plinth height allowing patient's hips, knees, and ankles to be positioned at an angle reached 90 degrees, and both patient's feet were positioned flatly on the floor.
- *Item/grade II of MFACT:* the tested ICUAWS patient could not perform 1-min sitting without external support (back/hand support). The tested ICUAWS patient was able to perform walking with the help of two persons.
- *Item/grade III of MFACT:* Only one person can manually help the tested ICUAWS patient during on-level surfaced ambulation/walking to prevent any form of falling. Continuous and necessary manual help/contact from the assisting person is strongly needed to support during-ambulation ICUAWS patient's balance, body weight, and/or coordination.
- *Item/grade IV of MFACT:* Only one person can manually help the tested ICUAWS patient during on-level surfaced ambulation/walking to prevent any form of falling. Continuous or intermittent manual help/contact (in the form of light touch) from the assisting person may be needed to support during-ambulation ICUAWS patient's balance and/or coordination.
- *Item/grade V of MFACT:* During on-level surfaced ambulation/walking, the ICUAWS patient did not receive manual contact/support from an assistant person, but for safety concerns/reasons, the ICUAWS patient required standby verbal cuing or non-physical contact/guarding of one person only.
- *Item/grade VI of MFACT:* The turning, walking, and transfer activities were done independently by the ICUAWS patient on level ground. Ascending/descending stairs and walking on uneven surfaces or inclines needed negotiations such as therapist's supervision or physical assistance.
- *Item/grade VII of MFACT*: full ability to perform independent walking/gait on (non)level surfaces/inclines and stairs.

It is to be noted that MFACT did not take into consideration the use of assistive walking aids.

Secondary outcomes

Pulmonary functions

The predicate values of ICUAWS patients' forced vital capacity (FVC) test and the test of the forced expiratory volume (at the first second of ICUAWS patients' expiration) (FEV1) were assessed.

Arterial blood gases

For all included ICUAWS patients in this rehabilitation trial, besides the arterial oxygen saturation (SO_2), the arterial partial pressure of oxygen, and carbon dioxide (PO_2 and PCO_2) were assessed.

Respiratory muscle strength

According to the published guideline/recommendation of "American Thoracic Society and European Respiratory Society, 2002'" [12], utilizing MicroRPM portable/hand-held meter (respiratory pressure meter, CareFusion Micro-Medical, UK), ICUAWS patients' MIP and maximal expiratory pressure (MEP) were assessed/recorded in cm H2O.

ICUAWS patients' health-associated quality of life (QoL)

The QoL questionnaire, short-form-36 questionnaire (SF-36), is a general/valid patient-reported outcome assessment tool used in measuring ICUAWS patients' life satisfaction associated with their health. In this rehabilitation trial, the 36 SF-36-item questionnaire was eight subscales/subcategories: ICUAWS patient's physical role, ICUAWS patient's vitality, ICUAWS patient's social function, ICUAWS patient's emotional role, bodily discomfort/pain, ICUAWS patient's physical function, and ICUAWS patient's general mental health. Furthermore, the eight scales are combined to create the physical component summary and the mental component summary, and two SF-36-related separated high-order summary scales were constituted from the eight subscales/subcategories: physical summary (PS) and Mental summary (MS) [13].

Timed up-and-go test

Measured in seconds, ICUAWS patients' timed up-and-go test (TUGT) was assessed after recording the time consumed by the ICUAWS participants to do the following successive steps: rise from the test's standard armchair, perform 3-meter walking, make a turn, walk back to the test's chair, and then sit down [14]. Patients who achieved grade I, II, or III using MFACT were given a score of zero in TUGT.

Six-minute walk test (SMWT)

Measured in meters, ICUAWS patients' walking distance during 6-min walking was assessed. Patients who achieved grade I, II, or III using MFACT were given a score of zero in SMWT.

Ten-meter walk test (TMWT)

Measured in seconds, ICUAWS patients' walking time to cover a 10-m walk was assessed. Patients who achieved grade I, II, or III using MFACT were given a score of zero in TMWT.

Thirty-second sit-to-stand test (30sSTST)

ICUAWS patients' number of performed sit-to-stand repetitions covered during 30 s were assessed during 30sSTST. Patients who achieved grade I, II, or III using MFACT were given a score of zero in TMWT.

Blinding

The details of physiotherapeutic interventions (IMT, traditional IMT, routine chest physiotherapy, resisted upper and lower limb exercises, neuromuscular electrical stimulation) applied to ICUAWS patients were not informed to outcome assessors.

Sample size

The persons of ICUAWS who completed this study were 40 ICUAWS patients. In fact, this number was 36 persons (this was the initial number that was delivered from a pilot power-analysis test on 16 ICUAWS sufferers, effect size 0.93, 80% power), but it was increased by 10% to 40 ICUAWS sufferers to eliminate the effect of patients' discontinuation during the rehabilitation period.

Statistical analysis of this ICUAWS trial

Normality test of basic (age, days of mechanical ventilation, age, BMI) and outcome data (PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS) of ICUAWS patients showed normal distribution by Kolmogorov–Smirnov test. Considering that the common/international significant effect of P value was < 0.05 for all ICUAWS trial's data, utilizing the SPPS 18, unpaired (for between-group parity/comparison of ICUAWS elderly's basic data) and ANOVA (for within-group or between-group parity/comparison of ICUAWS elderly's outcomes) tests were practiced during data analysis of this ICUAWS trial.

Results

Pre-treatment between-group comparison of ICUAWS patients' basic (age, days of mechanical ventilation, and BMI as pointed in Table 1) and outcome data (PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS as pointed in Table 2) did not show a significant variation.

After ending the rehabilitative procedures in ICUAWS patients, the within-IMT-group comparison of outcome

Table 1 Basic data this inspiratory muscle rehabilitation trial in ICUAWS patients (expressed as percentage, mean ± SD, or numbers)

Data of ICUAWS patients	IMT group	Control group	*P* value
ICUAWS patients' age [year]	73.35 ± 5.24	71.60 ± 4.50	0.264
ICUAWS patients' MVD (days)	35.35 ± 11.82	36.45 ± 9.77	0.750
ICUAWS patients' body mass index [kg/m^2]	25.55 ± 2.57	24.51 ± 3.06	0.251
ICUAWS Males %	50	55	
Number of primary diagnosis in ICU	7	6	
	6	5	
	5	6	
	2	3	

ICU intensive care unit, non-significant *P* value is considered when the value is > 0.05, *MVD* mechanical ventilation duration, *IMT* inspiratory muscle training, *ICUAWS* intensive-care-unit acquired-weakness syndrome, *SD* standard deviation

data (PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS) showed a significant improvement. Regarding the within-control-group comparison, only TUGT, 30sSTST, MFACT, SMWT, PS, TMWT, MIP, and MS showed significant improvements (these improvements were lower than the IMT group's improvements as pointed out in Table 2).

After ending the rehabilitative procedures in ICUAWS patients, the between-group comparison of outcome data (PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS) showed a significant improvement toward the IMT group (as pointed in Table 2).

Discussion

This was the first trial that used IMT in the rehabilitation scenario of ICUAWS. Compared with the group of ICUAWS that received a traditional rehabilitation program only, the ICUAWS group that received both IMT and traditional rehabilitation program showed greater significant improvements in PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS.

The explanation of improved respiratory muscle strength (represented as MIP and MEP) after IMT may be a multifactorial mechanisms. Increased proportion/size of type-II respiratory muscle fibers, enhanced diaphragmatic thickness/strength, inhibited respiratory muscles' metaboreflex, and enhanced economical energy expenditure of respiratory muscle contraction are the suggested mechanism of IMT-induced improvement in MIP and MEP. Improved ICUAWS patients' respiratory muscle strength/capacity, by-respiratory-muscle lactate production, respiratory muscle oxygenation, and perception of dyspnea and respiratory muscle fatigue increase functional performance of peripheral muscles (including muscles of locomotion) increases, so the patients report elevated functional fitness, exercise tolerance, walking abilities, and quality of life [9, 15].

Besides the highly reported improvement in cardiopulmonary fitness that increases the utilization of locomotor muscles in walking and functional performance, exercise protocols of peripheral/limb muscles not only increase respiratory muscles strength/endurance but also add specific training of the respiratory muscles to peripheral muscle training generate more strength in chronic-disease patients' respiratory muscles [16]. So, these explanations may justify the improved gait disabilities after adding IMT to the traditional rehabilitation program of ICUAWS.

Regarding arterial blood gases, the ICUAWS patients' improved PO_2, PCO_2, and SO_2 after a 4-week IMT may be related to the consequent reduction of breath workloads, positive changes in ventilator pattern, and improved correction of ICUAWS patients' respiratory pattern/manner from high-energy costing rapid/shallow respiratory pattern to low-energy costing slow/deep respiratory pattern [17].

Consistent with the ICUAWS patients' findings, the COPD patients' PO_2 and PCO_2 significantly responded well to the 2-month IMT training in a study conducted by Aly et al. [17]. In adherence with us, results of hemodialysis patients' SO_2, PO_2, SMWT, and PCO_2 significantly responded well to the 2-month IMT (via incentive spirometer) in a study conducted in 2021 [18].

The 8-week IMT protocol for strengthening older women's respiratory muscles significantly improved their MIP and MEP to support us [15]. After 12-week IMT, the atrial fibrillation patients' MEP, FVC, SMWT, FEV1, and MEP significantly improved [19] parallel to our ICUAWS patients' findings. The 6-week trial conducted in 2022 on stroke patients showed a significant improvement in SMWT, MEP, TUGT, and MIP after the IMT protocol to be consistent with our IMT protocol's results [20].

Besides MIP improvement, engagement time in physical activity and after-exercise fatigue time was significantly increased after 8-week IMT in moderately active elderly

Table 2 Outcomes of this inspiratory muscle rehabilitation trial (mean ± SD)

Parameters		IMT group	Control group	*P* value (between IMT and control groups)
FVC (% predicted)	Pre-rehabilitation program	69.90 ± 6.75	67.60 ± 5.78	0.255
	Post-rehabilitation program	73.55 ± 6.36	68.60 ± 6.26	0.018*
	P value (within rehabilitation groups)	< 0.001*	0.09	
TUGT (measured in seconds)	Pre-rehabilitation program	20.35 ± 5.70	24.10 ± 9.05	0.125
	Post-rehabilitation program	10.10 ± 3.98	16.90 ± 6.91	< 0.001*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
FEV1 (% predicted)	Pre-rehabilitation program	71.30 ± 5.91	68.85 ± 7.06	0.242
	Post-rehabilitation program	75.75 ± 5.71	69.55 ± 6.03	0.002*
	P value (within rehabilitation groups)	< 0.001*	0.188	
PO_2 (mmHg)	Pre-rehabilitation program	93.70 ± 3.19	91.30 ± 5.22	0.088
	Post-rehabilitation program	95.10 ± 2.55	91.50 ± 6.53	0.027*
	P value (within rehabilitation groups)	0.028*	0.746	
30sSTST (repetitions managed in 30 s)	Pre-rehabilitation program	15.25 ± 2.24	13.90 ± 2.10	0.057
	Post-rehabilitation program	17.80 ± 2.09	14.95 ± 2.16	< 0.0001*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
PCO_2 (mmHg)	Pre-rehabilitation program	41.10 ± 4.25	43.60 ± 3.71	0.055
	Post-rehabilitation program	39.80 ± 4.40	43.35 ± 6.06	0.041*
	P value (within rehabilitation groups)	0.044*	0.691	
MFACT	Pre-rehabilitation program	2.55 ± 1.09	2.65 ± 1.13	0.779
	Post-rehabilitation program	5.65 ± 1.18	3.75 ± 1.06	< 0.001*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
SO_2 (%)	Pre-rehabilitation program	94.05 ± 1.60	95.15 ± 2	0.063
	Post-rehabilitation program	97.25 ± 2.44	95.25 ± 2.61	0.017*
	P value (within rehabilitation groups)	< 0.001*	0.875	
SMWT (measured in meters)	Pre-rehabilitation program	135.45 ± 46.45	118.30 ± 35.51	0.197
	Post-rehabilitation program	288.40 ± 55.24	250.60 ± 44.46	0.022*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
MIP (cm H_2O)	Pre-rehabilitation program	34.85 ± 4.69	31.30 ± 7.10	0.07
	Post-rehabilitation program	37.95 ± 4.18	31.55 ± 6.71	0.001*
	P value (within rehabilitation groups)	< 0.001*	0.680	
TMWT (measured in seconds)	Pre-rehabilitation program	14.35 ± 2.49	16.10 ± 3.22	0.063
	Post-rehabilitation program	7.05 ± 1.63	11.75 ± 3.22	< 0.001*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
PS	Pre-rehabilitation program	22.35 ± 6.45	26.30 ± 6.10	0.054
	Post-rehabilitation program	25.75 ± 6	29.65 ± 6.08	0.048*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
MEP (cm H_2O)	Pre-rehabilitation program	33.50 ± 6.36	29.90 ± 7.89	0.121
	Post-rehabilitation program	38.30 ± 5.94	30.95 ± 7.82	0.002*
	P value (within rehabilitation groups)	< 0.001*	< 0.001*	
MS	Pre-rehabilitation program	49.25 ± 5.28	46.40 ± 4.33	0.07
	Post-rehabilitation program	54.35 ± 5.22	47.45 ± 4.35	< 0.001*
	P value (within rehabilitation groups)	< 0.001*	0.003*	

FEV1 forced expiratory volume in the patients' first second of expiration, *30sSTST* thirty-second sit-to-stand test, *MIP* maximal inspiratory pressure, *IMT* inspiratory muscle training, *SMWT* six-minute walking test, *SD* standard deviation, SO_2 oxygen saturation, *P value is significant, *MS* Mental Summary of Short Form 36, PO_2 partial pressure of oxygen, *TUGT* time up-and-go test, PCO_2 partial pressure of carbon dioxide; *MFACT* Modified Functional Ambulation Category Test, *PS* Physical Summary of Short Form 36, *MIP* maximal inspiratory pressure, *FVC* forced vital capacity, *TMWT* ten-meter walking test

[16]. Also, functional capacity and limitations due to physical factors (as two domains of an eight-domain SF-36 QoL questionnaire), MIP, and 30sSTST significantly improved in institutionalized Brazilian elderly after 6-week IMT [21].

The results of 8-week IMT in type diabetics were concurrent with our ICUAWS patients' recorded results because the diabetics showed significant improvements in MIP, TUGT, and SMWT [22]. Outcomes of applying 8-week IMT in multiple sclerosis patients were concurrent with us due to FEV1, MEP, TUGT, FVC, and MIP, all domains of the SF-36 QoL questionnaire [23].

Limitations

Despite the well-applied randomization and blinding of this study, tracking changes in PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS after the trial termination was the main limitation. Perspective and randomized future IMT trials in ICUAWS patients should manage/test effect of different types of respiratory muscle trainer devices in ICUAWS patients.

As seen in different settings and circumstances [24–26], examining the efficacy of the unsupervised home sessions [24], tele-rehabilitation [25], or robot-assisted rehabilitation [26] must be examined, but in ICUAWS survivors.

Conclusion

Adding IMT protocol to traditional rehabilitation programs improves ICUAWS patients' PS, PO_2, TUGT, PCO_2, FEV1, 30sSTST, FVC, SO_2, MFACT, SMWT, MIP, TMWT, MEP, and MS.

Acknowledgements The authors are thankful to the Deanship of Graduate Studies and Scientific Research at University of Bisha for supporting this work through the Fast-Track Research Support Program.

Author contribution AM, EHF, and IA contributed equally in all parts of this study performed on older sufferers with ICUAWS. All three authors of ICUAWS trial authorize the responsibility of the content of this paper.

Data Availability Up on request.

Declarations

Ethics approval Helsinki rules for applying/performing clinical trials/research are considered. The unique code of local ethical Cairo-university approval was P.T.REC/012/004624.

Consent to participate All ICUAWS older patients were consented.

Informed consent The unique code of local ethical Cairo-university approval that allowed consenting of patients was P.T.REC/012/004624.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

1. Yosef-Brauner O, Adi N, Ben Shahar T, Yehezkel E, Carmeli E (2015) Effect of physical therapy on muscle strength, respiratory muscles and functional parameters in patients with intensive care unit-acquired weakness. Clin Respir J 9(1):1–6. https://doi.org/10.1111/crj.12091
2. Hermans G, Van den Berghe G (2015) Clinical review: intensive care unit acquired weakness. Crit Care 19(1):274. https://doi.org/10.1186/s13054-015-0993-7
3. Needham DM, Davidson J, Cohen H, Hopkins RO, Weinert C, Wunsch H, Zawistowski C, Bemis-Dougherty A, Berney SC, Bienvenu OJ, Brady SL, Brodsky MB, Denehy L, Elliott D, Flatley C, Harabin AL, Jones C, Louis D, Meltzer W, Muldoon SR, Palmer JB, Perme C, Robinson M, Schmidt DM, Scruth E, Spill GR, Storey CP, Render M, Votto J, Harvey MA (2012) Improving long-term outcomes after discharge from intensive care unit: report from a stakeholders' conference. Crit Care Med 40(2):502–509. https://doi.org/10.1097/CCM.0b013e318232da75
4. Taylor C (2023) Intensive care unit-acquired weakness. Anaesth Intensive Care 25(1):1–4. https://doi.org/10.1016/j.mpaic.2023.10.002
5. Alvarenga GM, Charkovski SA, Santos LKD, Silva MABD, Tomaz GO, Gamba HR (2018) The influence of inspiratory muscle training combined with the Pilates method on lung function in elderly women: a randomized controlled trial. Clinics (Sao Paulo) 73:e356. https://doi.org/10.6061/clinics/2018/e356
6. Mills DE, Johnson MA, Barnett YA, Smith WH, Sharpe GR (2015) The effects of inspiratory muscle training in older adults. Med Sci Sports Exerc 47(4):691–697. https://doi.org/10.1249/MSS.0000000000000474
7. Seixas MB, Almeida LB, Trevizan PF, Martinez DG, Laterza MC, Vanderlei LCM, Silva LP (2020) Effects of inspiratory muscle training in older adults. Respir Care 65(4):535–544. https://doi.org/10.4187/respcare.06945
8. Silva CMDSE, Gomes Neto M, Saquetto MB, Conceição CSD, Souza-Machado A (2018) Effects of upper limb resistance exercise on aerobic capacity, muscle strength, and quality of life in COPD patients: a randomized controlled trial. Clin Rehabil 32(12):1636–1644.https://doi.org/10.1177/0269215518787338
9. Kaeotawee P, Udomittipong K, Nimmannit A, Tovichien P, Palamit A, Charoensitisup P (2022) Effect of threshold inspiratory muscle training on functional fitness and respiratory muscle strength compared to incentive spirometry in children and adolescents with obesity: a randomized controlled trial. Front Pediatr 10:942076. https://doi.org/10.3389/fped.2022.942076
10. Park CS, An SH (2016) Reliability and validity of the modified functional ambulation category scale in patients with hemiparalysis. J Phys Ther Sci 28(8):2264–2267. https://doi.org/10.1589/jpts.28.2264
11. Chau MWR, Chan SP, Wong YW, Lau MYP (2013) Reliability and validity of the modified functional ambulation classification in patients with hip fracture. Hong Kong Physiother J 31(1):41–44. https://doi.org/10.1016/j.hkpj.2013.01.041
12. American Thoracic Society/European Respiratory Society (2002) ATS/ERS Statement on respiratory muscle testing. Am J Respir Crit Care Med 166(4):518–624. https://doi.org/10.1164/rccm.166.4.518
13. Tarlov AR, Ware JE Jr, Greenfield S, Nelson EC, Perrin E, Zubkoff M (1989) The medical outcomes study. An application

of methods for monitoring the results of medical care. JAMA. 262(7):925–930. https://doi.org/10.1001/jama.262.7.925
14. Podsiadlo D, Richardson S (1991) The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39(2):142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x
15. Souza H, Rocha T, Pessoa M, Brandão D, Fregonezi G, Campos S, Aliverti A, Dornelas A (2014) Effects of inspiratory muscle training in elderly women on respiratory muscle strength, diaphragm thickness and mobility. J Gerontol A Biol Sci Med Sci 69(12):1545–1553. https://doi.org/10.1093/gerona/glu182
16. Aznar-Lain S, Webster AL, Cañete S, San Juan AF, López Mojares LM, Pérez M, Lucia A, Chicharro JL (2007) Effects of inspiratory muscle training on exercise capacity and spontaneous physical activity in elderly subjects: a randomized controlled pilot trial. Int J Sports Med 28(12):1025–10299. https://doi.org/10.1055/s-2007-965077
17. Aly FA, El-Saed AA, Shanub ASA (2007) Effect of inspiratory muscle training on blood gases in patients with chronic obstructive lung disease. Bull Fac Phys Ther Cairo Univ 12(2):225–233
18. Aboelmagd F, Ismail SM (2021) Impact of inspiratory muscle training on diaphragmatic mobility and arterial blood gases in patients undergoing haemodialysis. Int J Ther Rehabilit. https://doi.org/10.12968/ijtr.2020.0030
19. Zeren M, Demir R, Yigit Z, Gurses HN (2016) Effects of inspiratory muscle training on pulmonary function, respiratory muscle strength and functional capacity in patients with atrial fibrillation: a randomized controlled trial. Clin Rehabil 30(12):1165–1174. https://doi.org/10.1177/0269215515628038
20. Aydoğan Arslan S, Uğurlu K, Sakizli Erdal E, Keskin ED, Demirgüç A (2022) Effects of inspiratory muscle training on respiratory muscle strength, trunk control, balance and functional capacity in stroke patients: a single-blinded randomized controlled study. Top Stroke Rehabil 29(1):40–48. https://doi.org/10.1080/10749357.2020.1871282
21. Vilaça AF, Pedrosa BCDS, Amaral TCN, Andrade MDA, Castro CMMBD, França EETD (2022) The effect of inspiratory muscle training on the quality of life, immune response, inspiratory and lower limb muscle strength of older adults: a randomized controlled trial. Revista Brasileira de Geriatria e Gerontologia 22(6):e190157. https://doi.org/10.1590/1981-22562019022.190157
22. Albarrati A, Taher M, Nazer R (2021) Effect of inspiratory muscle training on respiratory muscle strength and functional capacity in patients with type 2 diabetes mellitus: a randomized clinical trial. J Diabetes 13(4):292–298. https://doi.org/10.1111/1753-0407.13106
23. Ghannadi S, Noormohammadpour P, Mazaheri R, Sahraian MA, Mansournia MA, Pourgharib Shahi MH, Salmasi Fard AH, Abolhasani M (2022) Effect of eight weeks respiratory muscle training on respiratory capacity, functional capacity and quality of life on subjects with mild to moderate relapsing-remitting multiple sclerosis: a single-blinded randomized controlled trial. Mult Scler Relat Disord 68:104208. https://doi.org/10.1016/j.msard.2022.104208
24. Ismail AMA (2022) Stress axis response to aerobic exercise in chronic obstructive pulmonary disease patients. Advances in Rehabilitation 36(4):24–32. https://doi.org/10.5114/areh.2022.123180
25. Ismail AMA (2020) Cancelled elderly exercise sessions during the COVID-19 crisis: can physical therapists help from their homes? Eur J Physiother 22(4):235–235. https://doi.org/10.1080/21679169.2020.1775293
26. Ismail AMA (2021) Robot-assisted rehabilitation: it is the time for utilisation in in-patient health care facilities to maintain the activity of the elderly during the COVID-19 pandemic. Int Marit Health 72(1):80–81. https://doi.org/10.5603/IMH.2021.0013

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

View publication stats