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Effect of a quality improvement program on weaning from mechanical ventilation: a cluster randomized trial

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Take-home message: A quality improvement program as described here is an important measure in introducing an evidence-based mechanical ventilation weaning protocol into the practice setting. A multifaceted quality improvement intervention can be associated with significant improvements in clinical outcomes and hospital utilization.

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Electronic supplementary material
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Abstract *Purpose:* To evaluate the efficacy of a quality improvement (QI) program for protocol-directed weaning from mechanical ventilation. *Methods:* This was a prospective, cluster randomized controlled trial. The study consisted of a baseline phase and a QI phase. Fourteen intensive care units (ICUs) in Beijing, China, were randomized into the QI group and non-QI group. The QI group received a QI program to improve the compliance with protocol-directed weaning during the QI phase. *Results:* A total of 444 patients were enrolled in the non-QI group (193 for the baseline, 251 for the QI phase) and 440 in the QI group (199 for the baseline, 241 for the QI phase). During the QI phase in the QI group, compared with the non-QI group, total duration of mechanical ventilation decreased from 7.0 to 3.0 days ($p = 0.003$), the time before the first weaning attempt decreased from 3.63 to 1.96 days ($p = 0.003$), length of ICU stay decreased from 10.0 to 6.0 days ($p = 0.004$), length of hospital stay decreased from 23.0 to 19.0 days ($p < 0.001$). These differences were also significant in the QI group when the QI phase was compared with the baseline phase. In addition, there was a significant reduction in the percentage of mechanical ventilation exceeding 21 days ($p = 0.001$) when the baseline phase was compared with the QI phase in the QI group. *Conclusions:* The QI program involving protocol-directed weaning is associated with beneficial clinical outcomes in mechanically ventilated patients.

Keywords Mechanical ventilation · Ventilator weaning · Quality improvement · Critical care · Intensive care units · Randomized controlled trial

Introduction

Mechanical ventilation is invasive, expensive, and associated with potentially serious complications [1–4]. Hence, it is a high priority to identify strategies that reduce the duration of mechanical ventilation. Plenty of evidence has suggested that protocol-directed weaning should be an effective strategy and should be implemented for managing mechanical ventilation [1, 5]. In fact, although the use of weaning protocols has been recommended in clinical guidelines [6–8], the practical application of these protocols was often delayed and may not be utilized fully, if at all. Ely et al. [9] reported that after completion of several educational sessions for healthcare workers before implementation of protocol-directed weaning, full compliance was initially 10 % and only improved to 30 % with additional educational sessions. Li et al. [10] conducted a questionnaire in intensive care unit (ICU) staff from tertiary hospitals in 30 provinces and municipalities of China, finding that only 40.9 % performed a spontaneous breathing trial (SBT) before weaning, while the proportion of those that did not know, never performed, or occasionally performed an SBT was 13.4, 12.8, and 25.4 %, respectively. Hence, improving the translation of research findings into clinical practice, and thereby improving patient outcomes, presents many challenges.

Quality improvement (QI) is defined here as systematic, data-guided activities designed to bring about immediate improvements in healthcare delivery in particular settings [11]. Several randomized controlled trials have revealed that QI intervention could improve the processes [12–16] and outcomes [17, 18] of caring for critically ill patients. Although the same positive outcomes were found in mechanically ventilated patients in previous studies [19–22], those were all based on non-randomized trials with historical controls. The design might overestimate the effect of the intervention and may not be sufficient to establish a causal relationship between the interventions and the beneficial outcomes. The purpose of our study was to conduct a cluster randomized controlled trial to examine the effect on clinical outcomes of implementing a QI program aiming to improve the compliance with protocol-directed weaning.

Methods

Ethical approval

Ethics approval was obtained from Fuxing Hospital, Capital Medical University (FXHEC-KY2011038) and all participating sites. The need for informed consent was waived on the basis that the intervention was a quality improvement initiative.

ICUs and participants

Fourteen tertiary teaching hospital ICUs were recruited by direct invitation to participate in the study. They were all intensivist-run closed ICUs and had full-time intensivists and 24-h coverage. Most intensivists remained in the ICUs for their entire working hours, and 2–3 of them stay overnight. The intensivists attended structured twice-daily bedside rounds that last about 2 h. The operation of mechanical ventilators can be implemented by junior intensivists, but the decision about weaning and extubation was mainly made by senior intensivists.

Eligible patients were those admitted to the ICUs between October 2012 and October 2013 who required mechanical ventilation for greater than 24 h. The criteria for exclusion were patients transferred from other facilities who had already been intubated, dependence on mechanical ventilation for at least 2 weeks before enrollment, death within 24 h after ICU admission, Glasgow coma scale lower than 7, and enrollment in other studies that controlled weaning.

Baseline phase

The study was divided into two phases as shown in Fig. 1. During the baseline phase (8 October 2012 to 7 April 2013), data were collected in each participating ICU for 6 months as part of the baseline assessment. Before study initiation, a data collector was selected from each ICU to receive training in data collection. Patients' data, such as demographic characteristics, diagnoses, underlying diseases, mechanical ventilation settings, and outcome measures, were recorded using the standardized paper forms. It was specified not to implement management changes related to the study targets during the baseline observational period.

Randomization

A statistician who had no other involvement in the study allocated the ICUs to the QI group or non-QI group using a computer-generated randomization scheme. The coordinating center informed participating ICUs at the end of the baseline phase of their randomized allocation. As a result of the nature of the intervention, it was not possible to blind participants or those involved in providing the strategy. The study protocol is available from the Chinese clinical trials registry at www.chictr.org/cn/ (clinical trial number ChiCTR-TRC-00000532).

Weaning program development

The coordinating center and co-investigators from intervention ICUs participated in a 1-day weaning protocol

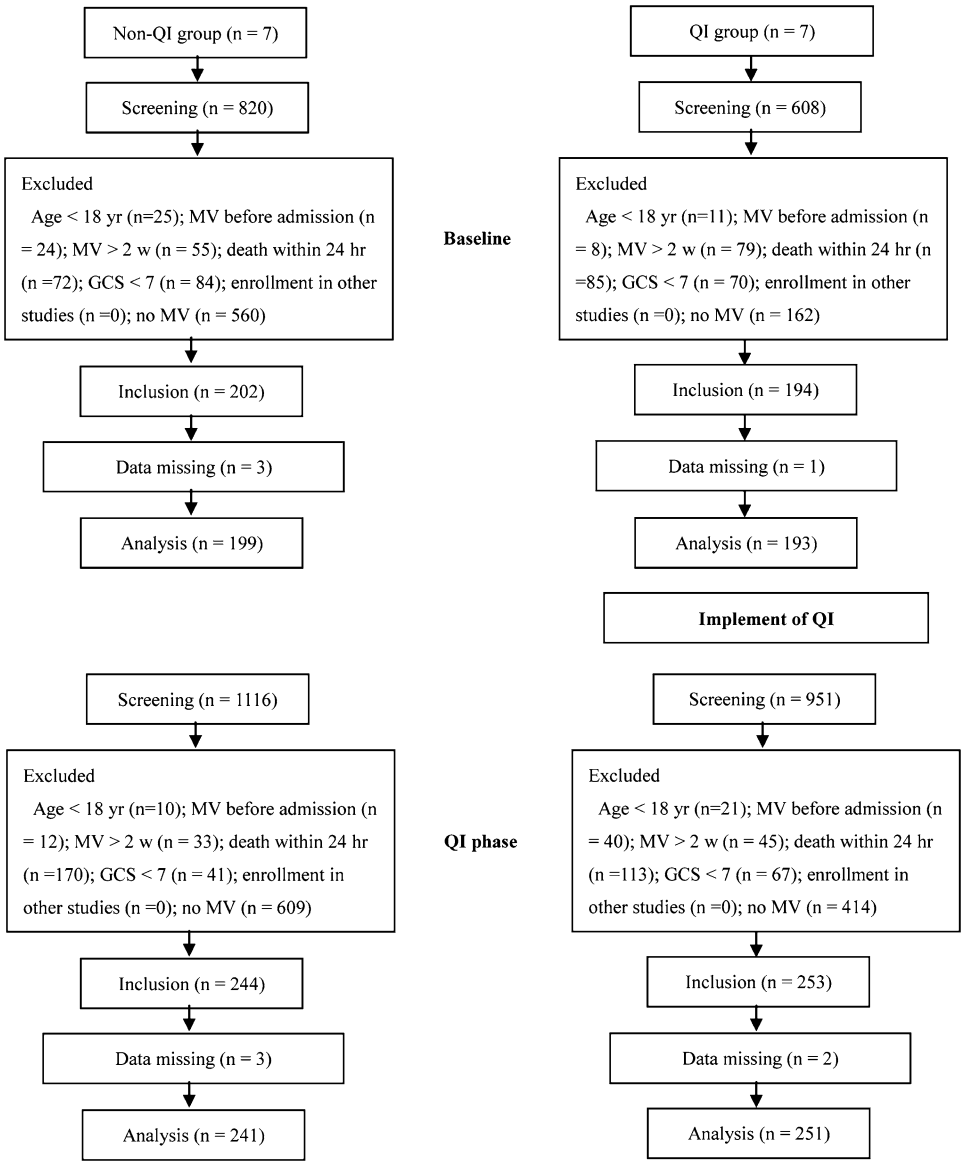

Fig. 1 Diagram showing flow of patients recruited. *QI* quality improvement, *ICU* intensive care unit, *MV* mechanical ventilation, *GCS* Glasgow coma scale

consensus conference in April 2013. The weaning protocol implemented in this study was developed according to the guidelines of mechanical ventilation in China [8] (Table 1).

QI interventions

The main elements of the QI program were delivered in the QI group during the QI phase (8 April 2013 to 7 October 2013) during which each center continued to collect data. The non-QI group did not receive any QI implication at any stage.

The QI program combined a series of evidence-based QI components—educational outreach visits [23], academic detailing [24], audit and feedback [25], and reminders [26, 27]—to facilitate the translation into practice of the protocol-directed weaning program.

At each intervention ICU, the project's chief investigator provided the relevant ICU staff with a formal educational session immediately before implementing the QI program to describe the study design, the necessity for QI, and detailed steps of how to implement the weaning protocol. The following educational outreach visit after 3 months was performed by the same chief investigator to increase trust in data quality, to identify potential deficiencies, and to optimize compliance with the weaning protocol. The coordinating center was responsible for monthly site inspections and audits of data collection at each ICU. Moreover, staff compliance with the weaning protocol was evaluated by reviewing 2–3 mechanical

Table 1 The weaning program implemented in this study

Screen 1: daily screening
All patients receiving mechanical ventilation should be assessed by using the following criteria from 0700 to 1700 hours every day
1. Resolution of the underlying cause for respiratory failure
2. Adequate cough
3. Adequate oxygenation: PaO_2/FiO_2 ratio >150; PEEP ≤5 cmH_2O; FiO_2 ≤0.4; and pH ≥7.25 (COPD patients: pH ≥7.30, PaO_2 >50 mmHg, FiO_2 ≤0.35)
4. Hemodynamic stability: the absence of active myocardial ischemia; and the absence of clinically significant hypotension (SBP >90 mmHg requiring no vasopressor or with only low-dose vasopressor such as dopamine or dobutamine, <5 μg/kg/min)
5. The capability to trigger the ventilator
If the patient meets all of the above criteria, progress to Screen 2
If the patient does not meet at least one of the above criteria, continue to ventilate the patient with the prior ventilator settings. Next day, the patients should be assessed again according to the above criteria
Screen 2: 3-min CPAP trial
Place the patient on CPAP at 5 cmH_2O, with prior FiO_2 level for 3 min
1. 8 bpm < RR < 35 bpm
2. Tidal volume >4 mL/kg
3. SpO_2 >90 %
4. HR <140 bpm or HR not changed >20 % or no new arrhythmias
If the patient meets all of the above criteria, progress to Screen 3
If the patient does not meet at least one of the above criteria, the patient was returned to the prior ventilator settings. Next day, the patients should be assessed again according to Screen 1 criteria
Screen 3: spontaneous breathing test, SBT
1. SpO_2 >90 %
2. RR <35 bpm or RR not changed >50 %
3. HR <140 bpm or HR not changed >20 % or no new arrhythmias
4. SBP <180 mmHg and >90 mmHg; BP not changed >20 %, no vasopressors required
5. No change in mental status (e.g., somnolence, coma, agitation, anxiety)
6. No respiratory distress (e.g., use of accessory muscle, abdominal paradox, diaphoresis)
Screen 3a: if the patient is ventilated <72 h, T-piece 3-8 LPM was suggested for 120 min
If the patient meets all of the above criteria, the intubation will be extubated
If the patient does not meet any of the above criteria, then the patient is returned to their prior ventilator settings. Next day, the patient should be assessed again according to Screen 1 criteria
Screen 3b: if the patient is ventilated ≥72 h or with severe heart and lung disease or failed T-piece SBT, PSV mode (PS at 8 cmH_2O and PEEP 5 cmH_2O) was suggested for 120 min
If the patient meets all of the above criteria, the patient will be extubated
If the patient does not meet any of above criteria, then add PS level to maintain RR within range 25–35 bpm and check the cause of failure. PS level can be reduced by 1–2 cmH_2O every 2 h. Next day, the patients should be assessed again according to Screen 1 criteria

A junior intensivist can make the actual decision about weaning and extubation if the patient meets the corresponding criteria, without the permission of senior intensivist

CPAP continuous positive airway pressure, *PEEP* positive end-expiratory pressure, *PS* pressure support, *PSV* pressure support ventilation, *RR* respiratory rate, *SBP* systolic blood pressure, *HR* heart rate, *SpO_2* oxygen saturation

ventilation documentation forms and progress notes during the QI phase for the QI group.

Each intervention ICU was asked to set up a local QI team involving a senior intensivist and a junior intensivist and to nominate the senior intensivist as the local opinion leader who took charge of change initiatives [28, 29]. The local opinion leader learned the content of the weaning protocol and was provided with supporting documents and educational tools. Afterwards, he/she disseminated the information to their colleagues in the ICU. The local opinion leader was instructed to organize at least one monthly interactive workshop among the involved ICU staff to assess the compliance with the weaning protocol, discuss the strengths and weaknesses in the current practice, and formulate strategies to improve practice. In addition, one-on-one meetings were held on request to provide opportunities for discussing any staff members who were reluctant to adopt the weaning protocol and for encouraging changes by providing scientific evidence.

Active reminders were made by the local leader who monitored compliance with the protocol on structured rounds and convinced his/her colleagues to follow the weaning protocol. As passive reminders, each intervention unit received a color poster that summarized the key steps of the weaning protocol and this was posted in high-traffic areas, by the patients' bedside, and next to each ICU computer station. Pocket cards were also given to the intensivists.

Outcome measures

The primary outcome was the total duration of mechanical ventilation. Secondary outcomes included the time before the first weaning attempt (the first weaning attempt

might be performed by standard SBT; if not, it might be performed by different weaning methods as ordered by the physicians, namely non-protocolized weaning), weaning time (defined as the time from the first weaning attempt to successful discontinuation of mechanical ventilation), and the length of stay in ICU and hospital, ICU mortality, hospital mortality, and 60-day mortality, and the frequency of complications (e.g., re-intubation, self-extubation, tracheotomy, and mechanical ventilation for ≥21 days).

Sample size and statistical analysis

An individually randomized trial would require 228 patients to detect a 1-day difference in total duration of mechanical ventilation at a 5 % significance level with 80 % power. Assuming an intra-cluster correlation coefficient of 0.06 (based on data from the pilot study) and 14 centers recruiting an average of 40 patients resulted in the sample size being inflated to 761. Accounting for a 15 % loss to follow-up resulted in a target of 876 recruited patients.

Data were presented as counts (percentages) for categorical variables, means (standard deviations) for normally distributed continuous variables, or medians (interquartile ranges) for other continuous variables. Baseline balance of proportions was assessed using the Chi-square test or Fisher's exact test, and continuous variables were assessed using two-tailed *t* tests or the Mann–Whitney *U* test, as appropriate. A two-tailed *p* value less than 0.25 was accepted to denote the presence of important confounding in baseline variables [30] which were adjusted using a multivariate model. The statistical analysis of outcome measures was done using generalized linear mixed methods with random effects to account for the cluster effect and confounding variables. All continuous outcome variables were positively skewed and were logarithmically transformed as target variables. Kaplan–Meier survival analyses were used to assess the probability of successful weaning over time. Cox proportional hazards modeling was used to assess differences between groups or phases after adjustment for baseline variables. The 238 patients who died during the study period were classified as censored cases as these patients had not undergone weaning from mechanical ventilation. A two-tailed *p* value of 0.05 or less was accepted to be statistically significant for the final analysis.

Results

A total of 884 patients were enrolled from 14 ICUs (7 in the QI group and 7 in the non-QI group). Among the participants, 440 were in the QI group (199 for the baseline phase, 241 for the QI phase) and 444 were in the non-QI group (193 for the baseline phase, 251 for the QI phase). A flowchart of patients screened is shown in Fig. 1. Baseline characteristics of the ICUs are described in Electronic Supplementary Material (ESM) 1. There was no crossover of patients, nurses, or physicians among the participating ICUs. The staffing pattern had no change before and after the intervention. Baseline characteristics of the patients are shown in Table 2. During the baseline phase, the non-QI group had more cardiovascular patients as compared with the QI group (52.8 vs. 43.2 %, $p = 0.056$) and the percentage of long-term dialysis patients in the non-QI group was larger during the QI phase than that during the baseline phase (14.5 vs. 9.2 %, $p = 0.08$). Patients were more likely to be admitted from a surgical ward (45.0 %) and to be in a postoperative state (35.9 %) for mechanical ventilation. There was a lower minimum PaO_2/FiO_2 in patients during the baseline phase.

Ninety-six case report forms indicated better compliance with the weaning protocol during the QI phase for the QI group. Daily screen was performed in 360 of 378 patient-days (95.2 %) of mechanical ventilation. After passing the daily screen, a 3-min continuous positive airway pressure (CPAP) test was followed in 230 of 239 patient-days (96.2 %). There were 161 patient-days that passed the CPAP test and subsequently 90.1 % of the patients underwent an SBT. Among the 56 patients who were successfully weaned from mechanical ventilation, 48 were extubated after the first SBT, 6 patients after the second SBT, and 2 patient after the third SBT.

The total median durations of mechanical ventilation during the baseline and QI phase were 8.25 and 7.0 days for the non-QI group and 5.92 and 3.0 days for the QI group, respectively. Compared with the baseline phase, there was a significant reduction in total duration of mechanical ventilation during the QI phase for the QI group ($p < 0.001$; Table 3; Fig. 2a), but not in the non-QI group. In addition, the total duration of mechanical ventilation significantly differed between the QI group and the non-QI group during the QI phase ($P = 0.003$; Table 3; Fig. 2a). Kaplan–Meier survival analysis showed that mechanical ventilation was successfully discontinued earlier during the QI phase for the QI group (Fig. 2b). After adjustment for baseline imbalance, a Cox proportional hazards analysis showed that mechanical ventilation was discontinued more rapidly in the QI group than in the non-QI group during the QI period (relative risk of successful weaning 1.07; 95 % confidence interval 1.03–1.10; $p < 0.001$) (ESM 2).

The time before the first weaning attempt showed significant improvement during the QI phase for the QI group as compared with the baseline phase ($p < 0.001$) and with the non-QI group ($p = 0.003$) (Table 3). There

Table 2 Characteristics of the study patients

Characteristics	QI group		Non-QI group		p value[c]	p value[d]	p value[e]	p value[f]
	Baseline phase ($n = 199$)	QI phase ($n = 241$)	Baseline phase ($n = 193$)	QI phase ($n = 251$)				
Age (years)	68 (52, 79)	71 (53, 80)	72 (59, 80)	72 (57, 79)	0.178	0.788	0.604	0.589
Female sex	70 (35.2)	89 (36.9)	67 (34.7)	94 (37.5)	0.924	0.703	0.552	0.905
Actual body weight (kg)	65 (58, 75)	65 (59, 75)	65 (57.3, 75)	65 (58, 72)	0.824	0.684	0.405	0.110
Height (cm)	170 (160, 173)	168 (160, 173)	170 (160, 175)	170 (160, 175)	0.402	0.461	0.655	0.196
APACHE II score	17 (11, 22)	16 (11, 21)	17 (12, 21)	16 (10, 25)	0.766	0.490	0.521	0.105
Routes of admission					0.850	0.939	0.630	0.506
Emergency department	51 (25.6)	67 (27.8)	53 (27.5)	83 (33.1)				
Medical ward	44 (22.1)	49 (20.3)	40 (20.7)	50 (19.9)				
Surgical ward	94 (47.2)	114 (47.3)	87 (45.1)	104 (41.4)				
Others	10 (5.0)	11 (4.6)	13 (6.7)	14 (5.6)				
Underlying disease								
Respiratory	29 (14.6)	20 (8.3)	30 (15.5)	30 (12.0)	0.788	0.037	0.272	0.180
Cardiovascular	86 (43.2)	121 (50.2)	102 (52.8)	123 (49.0)	0.056	0.144	0.422	0.790
Liver cirrhosis	5 (2.5)	1 (0.4)	3 (1.6)	5 (2.0)	0.724	0.059	0.731	0.216
Immunosuppression	34 (17.1)	40 (16.6)	41 (21.2)	46 (18.3)	0.295	0.892	0.443	0.614
Long-term dialysis	21 (10.6)	26 (10.8)	28 (14.5)	23 (9.2)	0.237	0.937	0.08	0.547
Diabetes mellitus	46 (23.1)	56 (23.2)	52 (26.9)	73 (29.1)	0.382	0.976	0.619	0.140
Smoking	81 (40.7)	80 (33.2)	71 (36.8)	88 (35.1)	0.426	0.104	0.707	0.663
Reasons for MV					0.619	0.263	0.278	0.220
ARDS	25 (12.6)	50 (20.7)	29 (15.0)	47 (18.7)				
Pneumonia	45 (22.6)	40 (16.6)	40 (20.7)	38 (15.1)				
COPD or asthma[a]	20 (10.1)	18 (7.5)	21 (10.9)	19 (7.6)				
Trauma	3 (1.5)	2 (0.8)	1 (0.5)	3 (1.2)				
Cardiopulmonary arrest	3 (1.5)	5 (2.1)	6 (3.1)	10 (4.0)				
Postoperative state	78 (39.2)	95 (39.4)	63 (32.6)	81 (32.3)				
Pulmonary edema	10 (5.0)	13 (5.4)	9 (4.7)	26 (10.4)				
Neurologic emergency	8 (4.0)	14 (5.8)	13 (6.7)	16 (6.4)				
Others	7 (3.5)	4 (1.7)	11 (5.7)	11 (4.4)				
Sedation/analgesia protocol	170 (85.4)	211 (87.6)	160 (82.9)	212 (84.5)	0.493	0.515	0.658	0.324
Mode of ventilation					0.108	0.335	0.518	0.397
VCV	32 (16.1)	49 (20.3)	28 (14.5)	50 (19.9)				
PCV	35 (17.6)	30 (12.4)	26 (13.5)	33 (13.1)				
PSV	52 (26.1)	55 (22.8)	41 (21.2)	39 (15.5)				
SIMV	15 (7.5)	13 (5.4)	8 (4.1)	13 (5.2)				
SIMV-PSV	62 (31.2)	91 (37.8)	85 (44.0)	111 (44.2)				
Others	3 (1.5)	3 (1.2)	5 (2.6)	5 (2.0)				
PaO_2/FiO_2 ratio[b]	226.0 (151.0, 303.0)	253 (180.0, 336.5)	210.0 (144.5, 274.0)	224 (170.0, 305.0)	0.119	0.051	0.050	0.062

Data are presented as median (interquartile range) for continuous outcomes and counts (proportions) for binary outcomes

APACHE II acute physiology and chronic health evaluation II, *MV* mechanical ventilation, *ARDS* acute respiratory distress syndrome, *COPD* chronic obstructive pulmonary disease, *VCV* volume-control ventilation, *PCV* pressure-control ventilation, *SIMV* synchronized intermittent mandatory ventilation, *PSV* pressure support ventilation, FiO_2 fraction of inspired oxygen, PaO_2 partial pressure of oxygen in arterial blood

[a] COPD/asthma exacerbation without infiltrates on chest X-ray

[b] Worst PaO_2/FiO_2 ratio recorded on the day of study inclusion

[c] Comparing 2 groups at baseline phase

[d] Comparing the QI phase with the baseline phase in the QI group

[e] Comparing the QI phase with the baseline phase in non-QI group

[f] Comparing 2 groups at QI phase

Table 3 Comparison of primary and secondary outcomes

End points	QI group	Non-QI group	*p* value[a]	*p* value[b]	*p* value[c]	*p* value[d]
Total duration of MV (days)						
Baseline phase	5.92 (2.75, 12.0)	8.25 (2.44, 15.44)	0.517	<0.001	0.456	0.003
QI phase	3.0 (1.75, 6.45)	7.0 (3.46, 13.5)				
Time before 1st weaning attempt (days)						
Baseline phase	3.0 (1.69, 6.63)	2.92 (1.08, 7.81)	0.801	<0.001	0.577	0.003
QI phase	1.96 (1.21, 3.52)	3.63 (1.83, 7.46)				
Weaning time (days)						
Baseline phase	2.4 (0.86, 13.47)	3.0 (0.4, 9.22)	0.144	0.122	0.621	0.825
QI phase	2.21 (0.8, 8.15)	2.13 (0.26, 8.43)				
Length of ICU stay (days)						
Baseline phase	8.0 (5.0, 19.0)	11.0 (5.0, 20.0)	0.764	<0.001	0.373	0.004
QI phase	6.0 (3.0, 12.0)	10.0 (6.0, 20.0)				
Length of hospital stay (days)						
Baseline phase	23.0 (14.0, 39.0)	24.0 (14.0, 39.5)	0.612	<0.001	0.934	<0.001
QI phase	19.0 (10.5, 30.0)	23.0 (15.0, 38.0)				
ICU mortality						
Baseline phase	69 (34.7)	71 (36.8)	0.965	0.107	0.292	0.822
QI phase	64 (26.6)	73 (29.1)				
Hospital mortality						
Baseline phase	74 (37.2)	74 (38.3)	0.877	0.118	0.294	0.924
QI phase	70 (29.0)	78 (31.1)				
60-day mortality						
Baseline phase	80 (40.2)	83 (43.0)	0.941	0.298	0.094	0.634
QI phase	81 (33.6)	81 (32.3)				
Re-intubation rate						
Baseline phase	14 (7.0)	10 (5.2)	0.417	0.265	0.134	0.654
QI phase	10 (4.1)	8 (3.2)				
Self-extubation						
Baseline phase	2 (1.0)	4 (2.1)	0.855	0.897	0.847	0.888
QI phase	1 (0.4)	3 (1.2)				
Tracheotomy						
Baseline phase	36 (18.1)	27 (14.0)	0.307	0.163	0.377	0.326
QI phase	29 (12.0)	46 (18.3)				
MV >21 days						
Baseline phase	32 (16.1)	21 (10.9)	0.125	0.001	0.881	0.052
QI phase	12 (5.0)	29 (11.6)				

Data are presented as median (interquartile range) for continuous outcomes and counts (proportions) for binary outcomes. All *p* values adjusted for baseline imbalance (i.e., variables $p < 0.25$ in Table 1) and cluster effects

QI quality improvement, *MV* mechanical ventilation, *ICU* intensive care unit

[a] Comparing 2 groups at baseline phase

[b] Comparing the QI phase with the baseline phase in the QI group

[c] Comparing the QI phase with the baseline phase in non-QI group

[d] Comparing 2 groups at QI phase

was no significant difference in weaning time between the two groups and between the two phases (Table 3).

The patients during the QI phase for the QI group had shorter ICU and hospital stay in both between-group comparison of the QI phase and intra-group comparison before and after the QI intervention (all $p < 0.001$; Table 3). There were no significant differences in the ICU, hospital, and 60-day mortality between the two phases and between the two groups (Table 3).

There were fewer patients during the QI phase for the QI group requiring mechanical ventilation for more than 21 days as compared with the baseline ($p = 0.001$) and with the non-QI group ($p = 0.052$) (Table 3). No significant differences were found in other complications between the two phases and between the two groups (Table 3).

Discussion

Our cluster randomized control trial assessed the effect of a comprehensive QI intervention that was focused on weaning from mechanical ventilation. We demonstrated that a QI program could lead to a significant decrease in total duration of mechanical ventilation, the time before the first weaning attempt, ICU and hospital length of stays, and percentage of the patients requiring long-term mechanical ventilation. These positive findings suggested the importance of a QI program to manage weaning from mechanical ventilation.

A before-and-after study investigated the effects of weaning protocol that was implemented as a hospital-wide QI program on clinical and economic outcomes. A

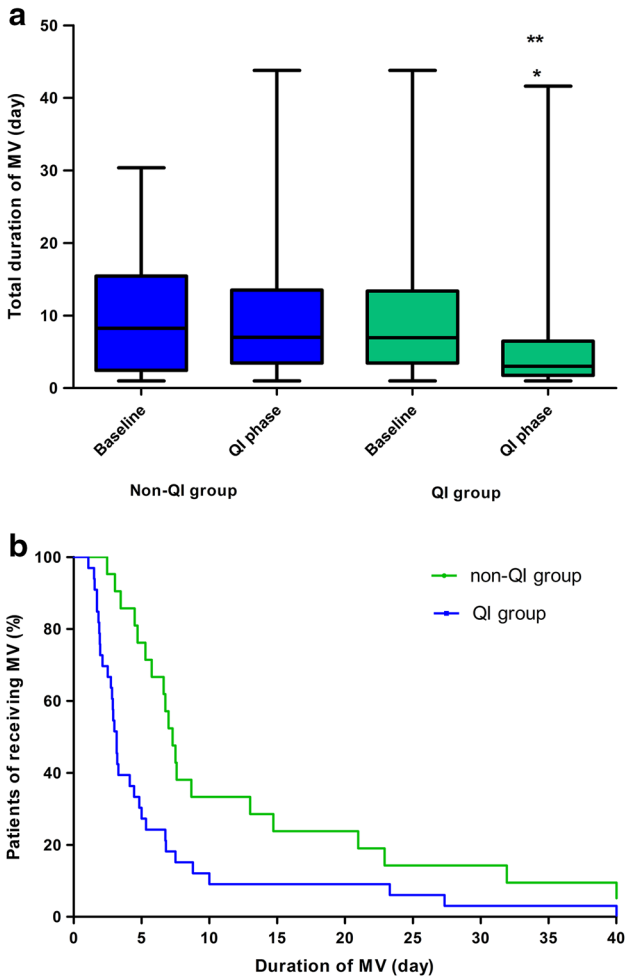

Fig. 2 **a** Box-and-whisker plot of total duration of mechanical ventilation. *Horizontal line* median; *box* 25th to 75th percentile; *whiskers* min and max values. *Comparing 2 groups at QI phase, $p = 0.003$; **comparing the QI phase with the baseline phase in the QI group, $p < 0.001$. **b** Kaplan–Meier analysis of the duration of mechanical ventilation at the QI phase

large reduction in the duration of mechanical ventilation, length of stay, percentage of patients requiring tracheotomy, and hospital costs was found when baseline was compared with the first 2 years after protocol implementation [19]. McLean et al. [20] reported an implementation program that was used to assess the effect on improving staff compliance with weaning protocol and clinical outcomes. After the intervention, the failed weaning rate decreased and the understanding of and compliance with the weaning protocol significantly improved. Another two observational studies [21, 22] also revealed the significant effect of a process improvement project on clinical and financial outcomes in mechanically ventilated patients.

However, previous QI studies typically applied before–after study designs, rendering them vulnerable to spurious causal inferences due to secular trends over time. To our knowledge, our study is the first cluster randomized controlled trial demonstrating that an evidence–practice gap in mechanical ventilation could be successfully addressed using a multifaceted practice change strategy. The study design was carefully developed to take account of known sources of bias in other randomized controlled trials conducted in this area. The appropriate methods were chosen for statistical analysis that was adjusted for the cluster randomization. The data were collected from daily clinical practice and the study was feasible for investigators, which ensured a complete follow-up period with relatively few missing data and high follow-up rates.

Without high compliance of ICU staff, the weaning protocol would be ineffective. In order to avoid the Hawthorne effect [31] and the contamination risk, we did not evaluate the weaning practice of the staff each time step by step during the baseline phase and the QI phase for the non-QI group. However, staff compliance with the weaning protocol was evaluated by a site inspection and review of the mechanical ventilation documentation form and progress notes during the QI phase for the QI group. The compliance with weaning protocol was higher than that reported in other studies [9, 32, 33]. Additionally, we adopted an intermediary process measure, i.e., the time before the first weaning attempt, so as to evaluate the compliance with weaning protocol by ICU staff. It was found in our study that the time before the first weaning attempt during the QI phase for the QI group was obviously shorter than the baseline phase or than the non-QI group, which further illustrated that staff awareness of weaning was improved via the QI intervention. Thus, the weaning process was accelerated. Other published studies also confirmed the reduction in the time before meeting weaning criteria in the protocolized weaning group [32, 34]. The QI program that was implemented in our study was an evidence-based process that guides healthcare teams in making procedural changes [23–29]. Therefore, it is reasonable to believe that the procedural changes achieved in the QI program could have been translated into improvement in clinical outcomes of patients.

Our study also has several limitations. First, although the randomized controlled design might help to reduce the probability of any systematic bias in patient selection or reporting, characteristics of the patient did not match well between the phases and groups. Although the APACHE II score was similar between the phases and between the groups, the PaO_2/FiO_2 was lower in patients during the baseline phase. However, we minimized the influence of this variability by adjusting imbalanced baseline variables in our multivariate analysis. Second, we recruited more patients on mechanical ventilation for less than 3 days who may be more easily weaned. The weaning protocols described in previous studies were most likely to be effective in surgical ICU patients [1]. Third, the observation of clinical practice for data collection may have

changed behavior both in the QI and non-QI group. For example, there was a reduction tendency in weaning time in the non-QI group when the QI phase was compared with the baseline phase. Therefore it was likely that Hawthorne effects [31] contributed toward the non-QI group during the QI phase. Finally, the QI intervention was delivered for a period of 6 months, whereas, in practice, QI should be an ongoing routine activity supported by healthcare institutions. The study was not designed to assess the effect of the QI intervention on clinical outcomes beyond the end of the study, but this could be the aim of larger longitudinal studies that evaluate QI in the future.

Conclusions

Our study has shown that a comprehensive QI intervention could improve the clinical outcome in mechanically ventilated patients. We speculate that this benefit may be attributed to the introduction of an evidence-based weaning protocol into the practice setting.

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Conflicts of interest The authors declare that they have no conflict of interest.

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