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Crew Resource Management in the Intensive Care Unit: a prospective 3-year cohort study

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Conflicts of interest

MH, a board-certified surgeon and retired Netherlands Royal Air Force pilot, has founded the Dutch organization "Wings of Care" with the aim to implement patient safety measures on a national level. The other authors have no conflict of interest to declare.

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Background: Human factors account for the majority of adverse events in both aviation and medicine. Human factors awareness training entitled "Crew Resource Management (CRM)" is associated with improved aviation safety. We determined whether implementation of CRM impacts outcome in critically ill patients.

Methods: We performed a prospective 3-year cohort study in a 32-bed ICU, admitting 2500–3000 patients yearly. At the end of the baseline year, all personnel received CRM training, followed by 1 year of implementation. The third year was defined as the clinical effect year. All 7271 patients admitted to the ICU in the study period were included.

The primary outcome measure was ICU complication rate. Secondary outcome measures were ICU and hospital length of stay, and standardized mortality ratio.

Results: Occurrence of serious complications was 67.1/1000 patients and 66.4/1000 patients during the baseline and implementation year respectively, decreasing to 50.9/1000 patients in the post-implementation year ($P = 0.03$). Adjusted odds ratios for occurrence of complications were 0.92 (95% CI 0.71–1.19, $P = 0.52$) and 0.66 (95% CI 0.51–0.87, $P = 0.003$) in the implementation and post-implementation year. The incidence of cardiac arrests was 9.2/1000 patients and 8.3/1000 patients during the baseline and implementation year, decreasing to 3.5/1000 patients ($P = 0.04$) in the post-implementation year, while cardiopulmonary resuscitation success rate increased from 19% to 55% and 67% ($P = 0.02$). Standardized mortality ratio decreased from 0.72 (95% CI 0.63–0.81) in the baseline year to 0.60 (95% CI 0.53–0.67) in the post-implementation year ($P = 0.04$).

Conclusion: Our data indicate an association between CRM implementation and reduction in serious complications and lower mortality in critically ill patients.

Editorial comment: what this article tells us

"Crew resource management" may be described as a systematic approach to implement a safety culture in a complex working environment. Now applied to intensive care medicine, it is both possible and necessary to make scientific evaluations, which remarkably enough are lacking in aircraft crew training programs.

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To err is human. As a result, everything that a human being devises, uses, or does is prone to error and failure. Human factors refer to environmental, organizational and job factors, and to human and individual characteristics which influence professional behavior in a way that affects performance and safety.¹ Human factors account for the majority of adverse events in aviation. Human factors awareness training entitled 'Crew Resource Management' (CRM) was introduced in 1979 for aircrew after a series of accidents in which human factors were found to be the root cause.² Following the implementation of CRM, a decrease in events led to CRM becoming the present day aviation operational standard.^{3,4} Especially during time critical cockpit emergencies, CRM is considered vital for aircrew effectiveness, although sound scientific proof of CRM effectiveness in aviation is lacking.

In clinical medicine, human factor-related errors can have a major impact on patient safety.^{5,6} This is especially so in departments where high risk, time critical procedures on vulnerable patients are performed in a multidisciplinary team setting; human factors are likely to play an important role.⁷ Indeed, in critically ill patients, the occurrence of complications is related to outcome.⁸

The defining aspect of CRM is a system approach to safety culture. Rather than focusing on individual failure, CRM aims to identify system flaws and uses standardized communication tools to improve process effectiveness and safety.⁹ The message of "good people are set up to fail in bad systems – let's figure out how to keep everyone safe" is more easily accepted than "you have a problem that needs to be corrected."¹⁰ This approach is fundamentally different from conventional quality and safety programs in medicine that focus on limiting variation in human behavior through regulations, or scenario-based team training, when these are not embedded in the more broad CRM approach.^{11,12} Contrary to aviation, there is currently no international standard for medical CRM training.

While the parallels between the critical processes in aviation and medicine suggest that a

well-adapted medical CRM training may have potential to improve patient safety, evidence of the effects of CRM on patient outcome in a clinical setting is limited. Closed format intensive care units (ICUs) facilitate both CRM implementation and effect evaluation. The aim of this study was to assess the effects of CRM implementation on outcome in critically ill patients.

Materials and methods

Department and training organization

Radboud University Medical Center (Radboudumc) is a 953 bed, tertiary-care academic hospital with approximately 32,000 admissions annually. The 32-bed ICU admits 2500–3000 patients yearly, of which approximately 1000 are cardio-thoracic surgery patients. Radboudumc's ICU workforce (in FTE) includes 16 consultants, 9 fellows, 22 residents, and a nursing staff of 173. The independent aerospace training organization that provided the CRM training consisted of five trainer/coaches (senior military and commercial airline pilots, psychologists and medical specialists of which some are dual-qualified). All were proficient in the area of operational human factors as well as CRM development and training.

CRM intervention

With the decision to implement CRM in the ICU, it was decided to evaluate its effects prospectively. Because of the nature of the intervention (team training), it was not feasible to perform a study using a control arm. For this reason, the pre-during-post design was chosen. Therefore, a 'baseline year', 'implementation year', and 'post-implementation year' were designated. In the 2 years preceding the study, we had a stable baseline complication rate, but as we could not perform data quality checks retrospectively, we decided not to use these data, and only use the prospective data obtained during the baseline year prior to implementation of CRM. At the end of the baseline year, all ICU personnel (attending physicians, nurses and residents) received a 2-day (9 contact hours per

day) CRM awareness training in multidisciplinary groups of a maximum of 15 participants within a 3-month window. All training sessions were conducted by two trainers and were held at a training facility at some distance to the Radboudumc campus to minimize interference. The course included lectures on human factors and principles of CRM, and multiple interactive sessions using realistic data such as case studies and video footage from the Radboudumc ICU department. The training emphasized eight key areas: situational awareness^{13,14} and recognition of adverse situations, human errors and non-punitive response, communication and briefing and debriefing techniques, providing and receiving performance feedback, management of stress, workload and fatigue, creating and maintaining team structure and climate, leadership in a flat hierarchy environment, and risk management and decision-making (see¹⁵ or Data S1 and Table S1). Each training group created a shortlist of practical “action points” to be used in the following implementation year, during which the CRM principles were forged into custom-made and practical clinical tools such as standardized briefings and debriefings, checklists, and noise (static) reduction methods. We considered the after-training follow-up to be crucial for the success of a CRM intervention.

The follow-up during the implementation year consisted of several measures: a “CRM Core Group” was formed, CRM became a standard item in staff meetings, non-facultative scenario-based team training sessions were planned, and CRM training was provided to all new personnel. Moreover, regular process observation took place.

The CRM Core Group consisted of three intensivists, 11 ICU nurses and the ICU’s patient safety officer. Under additional coaching from a CRM instructor, the Core Group coordinated translation of the CRM action points into clinical practice, and created professional ownership. This group interfaced regularly with the department’s medical and nursing staff and organized several activities such as a plenary kick-off meeting, an annual dedicated “week of CRM”, refresher lectures, and awarded the “CRM performer of the year”. The CRM Core Group posted regular information bulletins on the ICU intranet page and developed several checklists

for common ICU procedures, including central venous line placement, endotracheal intubation, tracheotomy, and handover during patient admission and transfer.

In addition, CRM became a standard agenda item during the 2-weekly staff meetings and yearly individual evaluations.

Furthermore, to secure the CRM lessons learned in daily practice, scenario-based team training was conducted during the implementation year. This team training was conducted in an in-hospital training location, using simulation manikins and CRM-trained clinical supervisors. As with the CRM training, the scenario-based team training was non-facultative, used a multidisciplinary setting, and involved the whole staff.

All new personnel (13 nurses and 2 intensive care fellows) also received the regular 2-day CRM training.

Finally, three times a year, during a 2-week period, designated senior ICU nurses were given the responsibility to observe an ICU unit whenever any invasive procedure took place. The resulting information was reported to the ICU’s safety officer, who presented the collected information to the CRM core team. No data were provided to the staff during the data collection period.

Data collection

Patient clinical outcome data were collected from the Dutch National Intensive Care Evaluation (NICE) database.¹⁶ The NICE classification system is not based on Clavien-Dindo or the AMA-master classification system. The Dutch ICU complication registration was developed by a subcommittee of the Dutch Society for Intensive Care Medicine and started with a questionnaire in which individual members were able to make suggestions for potential complications that should be included in the final registry. Of 68 potential complications, a final list was constructed by the subcommittee based on the following prerequisites: (1) existing evidence in the literature that the complication relates to patient damage, (2) complication must be either severe or frequent, (3) the complication must be clearly defined and measurable, and (4) the complication must be preventable by taking

appropriate measures. The final list was approved by all Dutch Society for Intensive Care Medicine members and included in the NICE registration.^{16,17}

All complications were registered daily by a consultant intensivist. To prevent incorrect (e.g. double) registration, the data were subsequently checked by the departmental database manager and rechecked by the national NICE organization. Furthermore, the NICE organization performs on-site data audits to monitor the quality of the data. Data were encrypted by the removal of all patient-identifying information. In the Netherlands, there is no need to obtain consent to use such registries with anonymous data. The NICE initiative is officially registered in accordance with the Dutch Personal Data Protection Act. The study was carried out in accordance with the applicable rules concerning the review of research ethics committees and informed consent. Data collection was standardized according to the strict definitions and was subject to stringent quality checks.

To determine the effect of CRM implementation on complication incidence, we used a predetermined set of 18 complications obtained from the NICE database.^{16,17} Data were collected during the baseline year preceding the 3-month CRM training phase (August 2009 to end of July 2010), the implementation year following the training phase (November 2010 to end of October 2011), and the post-implementation year (November 2011 to end of October 2012).

The primary outcome measure was overall ICU complication rate, of which the incidence of cardiac arrest and cardiopulmonary resuscitation (CPR) success rate had our special interest. Cardiac arrest incidence is considered a measure of quality of care¹⁸ and, as few clinical interventions rely on teamwork to such an extent as CPR, outcome was deemed a relevant endpoint as well. Secondary outcome measures were ICU and hospital length of stay, and standardized mortality ratio. Furthermore, as evidence from other critical industries¹⁹ and clinical settings^{20–23} suggests a positive relationship between safety climate and safety outcome, we measured the ICU's safety climate prior to and following the implementation year. Safety climate was determined by the Safety Attitudes Questionnaire (SAQ) using a Likert scale transformed to a

100-point scale.²⁴ The SAQ is a validated healthcare derivative of the Cockpit Management Attitudes Questionnaire.^{20,25} All CRM participants were invited to fill out a Dutch translation of the SAQ during the baseline year and at the end of the implementation year.

During the implementation period, process surveillance was conducted to monitor professional compliance: experienced observers scored 3–4 times per year during several weeks how many critical process opportunities suitable for CRM tools occurred and in what portion they were actually used.

Statistical analysis

Mann–Whitney *U*-tests were used to compare continuous data between two groups, Kruskal–Wallis tests were used to compare continuous data between three or more groups, and chi-square tests were used to compare proportions. We used an uncorrected chi-square test to evaluate our null hypothesis. In addition, multivariate logistic regression analysis was performed using APACHE IV probability score as a covariate to correct for differences in disease severity. To correct for possible differences in baseline patient characteristics, standardized mortality ratios (SMRs), their 95% CI, and differences between SMRs were calculated as described previously.^{26,27} A two-tailed *p*-value of less than 0.05 was considered statistically significant. Differences were not corrected for multiple testing because of the explorative nature of the study. With an estimated baseline complication rate of approximately 60–80/1000 patients, a power of 80%, and a two-sided alpha of 0.05, 2500 patients per cohort were required to detect an absolute change in complications of 20/1000 patients. Data were analyzed using SPSS Statistics 20 (IBM Corp., Armonk, NY, USA) and MedCalc 11.3.1.0 (MedCalc software, Oostend, Belgium).

Results

Patient data

The three cohorts consisted of 2295 (baseline year), 2423 (implementation year), and 2553 (post-implementation year) patients. During the

3-year study period, no relevant changes in staffing levels, device use, or protocols/procedures occurred, except for the ICU moving to another location in the hospital in December 2011.

Patient characteristics are listed in Table 1. A significant decrease in complication incidence rate was observed: from 67.1/1000 patients in the baseline year and 66.4/1000 patients in the implementation year to 50.9/1000 patients in the post-implementation year (Fig. 1, Table 2). Using the APACHE IV probability score as a covariate, the adjusted odd ratios for the occurrence of one or more complications were 0.92 (95% CI 0.71–1.19, $P = 0.52$) and 0.66 (95% CI 0.51–0.87, $P = 0.003$) in the implementation and post-implementation year, respectively.

Changes in the incidence per complication diagnosis are depicted in Table 2. The incidence of critical illness polyneuropathy/myopathy and cardiac arrests on the ICU decreased significantly. Using the APACHE IV probability score as a covariate, the adjusted odd ratios for critical illness polyneuropathy/myopathy were 0.52 (95% CI 0.25–1.06, $P = 0.07$) and 0.26 (95% CI 0.11–0.63, $P = 0.002$) in the implementation and post-implementation year, respectively. Adjusted odds ratios for cardiac arrests on the ICU were 0.87 (95% CI 0.47–1.62, $P = 0.66$) and 0.33 (95% CI 0.15–0.73, $P = 0.006$) in the implementation and post-implementation year, respectively. Aside from the decrease in incidence of cardiac arrests, the CPR success rate increased from 19% in the baseline year to 55% and 67% in the implementation and post-implementation year (Fig. 2). While there were small but statistical significant differences in patient characteristics regarding chronic cardiovascular disease (Table 1), this could not explain the reduced incidence and higher success rate of cardiac arrests in the post-implementation year, as chronic cardiovascular disease was not related to cardiac arrest across the three cohorts (phi coefficient of 0.014, $P = 0.24$).

As expected, the occurrence of complications was associated with mortality [APACHE IV adjusted odds ratio of 1.97 (95% CI 1.44–2.70, $P < 0.0001$)]. Finally, the standardized mortality ratio was 0.72 (95% CI 0.63–0.81) in the baseline year, 0.69 (95% CI 0.61–0.78) in the implementation year, and 0.60 (95% CI

0.53–0.67) in the post-implementation year (baseline vs. post-implementation year: $P = 0.04$).

No clinically relevant effects on ICU or hospital length of stay were observed.

Safety climate assessment

Following CRM implementation, perceived safety climate significantly improved in 5 of 6 Safety Attitudes Questionnaire-domains: team-work climate, safety climate, perceptions of management, working conditions, and job satisfaction (Table 3). Changes within disciplines (medical staff, nurses, other) are listed in Table S1 (Supplemental Digital Content).

Process surveillance

The surveillance from June to September 2012 showed that during 21 observational days, checklist use and briefings were performed in 70–90%. Debriefings were performed between 55% and 71%. Structured handovers scored between 55% and 70%.

Discussion

This study indicates an association between CRM implementation in the ICU and a lower incidence of predefined complications in critically ill patients. Of special interest, cardiac arrests on the ICU occurred less frequently following implementation of CRM, and a higher CPR success rate was observed.

In addition, we found that the occurrence of complications was associated with mortality and that implementation of CRM was associated with a reduced standardized mortality rate. These clinically relevant effects paralleled a positive impact on the perceived safety climate by the healthcare providers.

Several factors may explain the positive effects of CRM implementation on clinical end points in the present study. In the first place, we introduced CRM from the perspective of correcting system flaws rather than individual shortcomings, an approach which has been shown to be effective in convincing professionals.¹⁰ In addition, firm commitment and visible support from the department's leadership was present.^{10,15} Secondly, every CRM training was conducted

Table 1 Patient characteristics.

	Baseline year	Implementation year	Post-implementation year	<i>P</i> value
Number of ICU patients (<i>n</i>)	2295	2423	2553	
Age (year)	64 (53–73)	64 (53–73)	65 (54–73)	0.12
Female sex, <i>n</i> (%)	818 (35.6)	865 (35.7)	899 (35.2)	0.93
Weight (kg)	79 (70–89)	78 (69–88)	79 (70–90)	0.14
Height (cm)	172 (165–180)	173 (166–180)	174 (166–180)	0.049
Type of admission <i>n</i> (%)				
Medical	739 (32.2)	774 (31.9)	842 (33.0)	0.01
Elective surgery	1215 (52.9)	1364 (56.3)	1352 (53.0)	
Emergency surgery	341 (14.9)	285 (11.8)	359 (14.1)	
Chronic diagnoses, <i>n</i> (%)				
Chronic cardiovascular insufficiency	112 (4.9)	31 (1.3)	83 (3.3)	< 0.001
Respiratory insufficiency	65 (2.8)	45 (1.9)	68 (2.7)	0.07
Chronic renal insufficiency	91 (4.0)	86 (3.5)	114 (4.5)	0.26
Chronic dialysis	28 (1.2)	33 (1.4)	50 (2.0)	0.08
Metastatic malignancy	78 (3.4)	59 (2.4)	103 (4.0)	0.007
Hematological malignancy	70 (3.1)	59 (2.4)	54 (2.1)	0.11
Immunological insufficiency	78 (3.4)	107 (4.4)	135 (5.3)	0.006
AIDS	2 (0.1)	5 (0.2)	0 (0)	0.06
APACHE diagnosis group, <i>n</i> (%)				
Cardiovascular	1263 (55.0)	1336 (55.1)	1289 (50.5)	0.16
Gastrointestinal	175 (7.6)	174 (7.2)	211 (8.3)	
Genitourinary	55 (2.4)	59 (2.4)	64 (2.5)	
Hematology	16 (0.7)	17 (0.7)	20 (0.8)	
Metabolic	19 (0.8)	27 (1.1)	30 (1.2)	
Musculoskeletal/skin	34 (1.5)	43 (1.8)	51 (2.0)	
Neurological	301 (13.1)	305 (12.6)	334 (13.1)	
Respiratory	295 (12.9)	323 (13.3)	354 (13.9)	
Transplant	12 (0.5)	13 (0.5)	21 (0.8)	
Trauma	125 (5.4)	126 (5.2)	179 (7.0)	
Mechanical ventilation in first 24 h, <i>n</i> (%)	1932 (84.2)	2071 (85.5)	2059 (80.7)	< 0.001
Vasoactive medication, <i>n</i> (%)	992 (43.2)	1184 (48.9)	1000 (39.2)	< 0.001
APACHE IV score	53 (40–69)	63 (48–79)	66 (50–82)	< 0.001
APACHE IV probability score	0.05 (0.01–0.18)	0.07 (0.03–0.22)	0.09 (0.04–0.25)	< 0.001
SAPS	34 (27–44)	36 (30–46)	36 (29–46)	< 0.001
SAPS probability score	0.15 (0.08–0.33)	0.18 (0.11–0.37)	0.18 (0.37)	< 0.001
LODS	5 (4–7)	6 (5–8)	6 (4–8)	< 0.001
LODS probability score	0.21 (0.15–0.38)	0.29 (0.21–0.48)	0.29 (0.15–0.48)	< 0.001
MPM0	0.11 (0.07–0.22)	0.09 (0.06–0.20)	0.10 (0.06–0.22)	< 0.001
MPM24	0.24 (0.14–0.37)	0.25 (0.15–0.37)	0.23 (0.13–0.38)	0.10

Data are presented as median (interquartile range) or *n* (%). *P* value calculated by Kruskal–Wallis tests or chi-square tests.

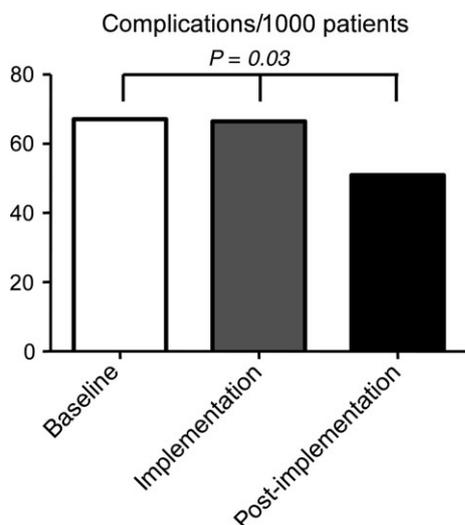


Fig. 1. Complications. Complication incidence per 1000 patients in the three cohorts. *P* value calculated using chi-square test.

by two trainers combining extensive operational experience in clinical medicine, military and commercial aviation, and cognitive psychology. As, in contrast to aviation, medical CRM has no accepted standard yet, their credible operational background was instrumental in convincing ICU professionals of the potential gains of CRM and implementing a new professional and team identity in a department. Thirdly, a core group of ICU professionals was formed to develop and integrate the new way of professional interaction within the ICU. As this group played a pivotal role in creating professional ownership, they received additional coaching from a CRM instructor during the implementation year and likely optimized training impact. Fourthly, to prevent dilution of human factors awareness the CRM intervention project included not only the initial training period but also the subsequent

Table 2 Complication incidence and outcome parameters.

	Baseline year	Implementation year	Post-implementation year	<i>P</i> value
Number of ICU patients	2295	2423	2553	
Line sepsis	3 (1.3)	7 (2.9)	3 (1.2)	0.29
Ventilator induced pneumonia	1 (0.4)	1 (0.4)	1 (0.4)	1.00
Decubitus (grade III/IV)	20 (8.7)	17 (7.0)	11 (4.3)	0.16
Unplanned extubation (self)	40 (17.4)	46 (19.0)	48 (18.8)	0.91
Unplanned extubation (other)	0 (0.0)	1 (0.4)	1 (0.4)	0.63
Acute myocardial infarction	13 (5.7)	27 (11.1)	23 (9.0)	0.12
Cardiac arrest	21 (9.2)	20 (8.3)	9 (3.5)	0.04
Pneumothorax (iatrogenous)	10 (4.4)	10 (4.1)	10 (3.9)	0.97
CVA (stroke)	1 (0.4)	2 (0.8)	4 (1.6)	0.43
Critical illness polyneuropathy/myopathy	21 (9.2)	12 (5.0)	7 (2.7)	0.01
Difficult intubation*	1 (0.4)	4 (1.7)	3 (1.2)	0.45
Loss of airway	3 (1.3)	0 (0.0)	4 (1.6)	0.17
Early tracheostomy-related hemorrhage	5 (2.2)	4 (1.7)	1 (0.4)	0.22
Late tracheostomy-related hemorrhage	2 (0.9)	1 (0.4)	1 (0.4)	0.73
Loss of airway during trachea canula-related procedure	1 (0.4)	0 (0.0)	0 (0.0)	0.34
Anatomical complications with tracheostomy	1 (0.4)	0 (0.0)	0 (0.0)	0.34
Vascular access problem	6 (2.6)	5 (2.1)	3 (1.2)	0.51
Gastrointestinal bleeding	5 (2.2)	4 (1.7)	1 (0.4)	0.22
Total no. of complications	154 (67.1)	161 (66.4)	130 (50.9)	0.03
ICU-LOS (days)	1.0 (0.8–3.0)	1.1 (0.8–3.0)	1.0 (0.8–2.8)	0.008
Hosp-LOS (days)	6.7 (3.7–15.2)	6.1 (3.1–13.8)	6.7 (3.5–13.4)	0.09
ICU mortality, <i>n</i> (%)	187 (8.1)	201 (8.3)	211 (8.3)	0.98
SMR	0.72 (95% CI 0.63–0.81)	0.69 (95% CI 0.61–0.78)	0.60 (95% CI 0.53–0.67)	0.04

Complication data are presented as: incidence (incidence/1000 patients). ICU-LOS, Hosp-LOS are presented as median (interquartile range). ICU mortality and Hosp mortality are presented as *n* (%). *P* value calculated by Kruskal–Wallis test or chi-square test, except for SMR data for which the difference between the baseline and post-implementation year was calculated as described previously.^{18,19} *Difficult intubation was defined as more than three intubation efforts or an intubation duration of > 10 min.

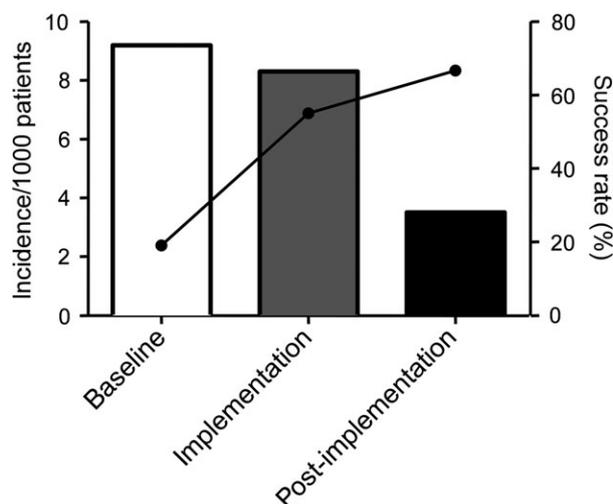


Fig. 2. Cardiopulmonary resuscitation. Cardiopulmonary resuscitation incidence (bars) and success percentage (dots/line) in the three cohorts. Cardiopulmonary resuscitation incidence significantly decreased ($P = 0.04$, chi-square test), while the success rate significantly increased ($P = 0.02$, chi-square test).

Table 3 Safety Attitudes Questionnaire (SAQ) scores of ICU professionals.

	Before CRM training ($n = 251$)	After CRM training ($n = 161$)	P value
Stress recognition	43 (0–90)	48 (1–84)	0.12
Teamwork climate	69 (38–90)	76 (38–100)	0.001
Safety climate	64 (29–97)	70 (29–94)	< 0.001
Perceptions of management	58 (17–84)	64 (27–84)	< 0.001
Working conditions	58 (17–86)	58 (11–90)	0.009
Job satisfaction	69 (43–90)	74 (43–95)	0.04

Data are represented as median (range). P value calculated by Mann–Whitney U -test. Response before and after CRM training was 72% and 51%, respectively. See Table S1 (Supplemental Digital Content) for SAQ scores per discipline.

training of new staff. Fifthly, some checklists were (re)designed. As checklists appear to be independent effective tools for improving patient safety,^{28,29} it is difficult to separate their impact on outcome from the CRM effort. In spite of the fact that we cannot exclude a positive influence of the (re)designed checklists on our results, we are convinced that the implementation of a checklist document has less effect on patient safety than the way the team works

with the document (e.g., briefing and crosscheck techniques inherent to CRM), especially because checklists were already in use at the department before the intervention. As we consider checklists a separate – valuable – safety tool, the CRM training focused on checklist use, not design.

Finally, to secure the CRM lessons learned in daily practice, scenario-based team training was conducted during the implementation year.^{15,30}

Several limitations of the present study need to be addressed. Most importantly, this study was a non-randomized, single-center study. The intensity and duration of the implementation process importantly limited the feasibility of other study designs. In spite of this limitation, we believe that the decrease in complication rate and SMR can be related to the CRM intervention. In the 2 years preceding the study baseline, complication rate was stable, but as these registrations could not be validated retrospectively, this data were not used. Furthermore, during the whole study period, there were no changes in interventions that are known to reduce morbidity or mortality in the ICU such as strict glucose regulation, early goal-directed therapy, use of corticosteroids, prone positioning, and low tidal volume ventilation. The fact that the ICU moved to another location in the hospital appears unlikely a confounder of our results, as no relevant changes in procedures, staffing levels, technical infrastructure, or other major changes that could influence patient management occurred. Nevertheless, some differences in patient characteristics between the different study periods were observed. It could be argued that the risk of a complication is related to the severity of illness. Importantly, after correction for severity of illness, implementation of CRM was still associated with a reduction in relevant complications and mortality. The additional association between the occurrence of a complication and mortality supports the notion that CRM accounts for the beneficial effects on mortality observed. In addition, the occurrence of critical illness polyneuropathy/myopathy is related to disease severity. As such, our finding of reduced incidence of critical illness polyneuropathy/myopathy is consistent with the notion that CRM is associated with improved care and reduced disease severity.

Nevertheless, we emphasize that a direct link between the reduced incidence and the CRM implementation is not possible.

We did not determine a direct link between a specific action and patient outcome, e.g., using data logging equipment (comparable to aviation's cockpit voice recording and flight data recording). Even though video logging of ICU procedures would be technically possible, there still is considerable reluctance in the medical professional community due to legal and patient privacy issues.³¹

Finally, because the Safety Attitude Questionnaire's response rate after training was relatively low (51%). Low response rates may increase the risk of a non-response bias.

Perceived safety climate is positively related to safety outcomes both in hospital settings and other high-hazard fields.^{21,32,33} Previous studies on the impact of safety climate on safety outcome have focused on either the effect of team training on perceived safety climate,^{34,35} or assessed patient outcome.³⁶ Implementation of CRM resulted in a culture change and a safer environment, illustrated by a decrease in malpractice expenses.³⁷ To our knowledge, our concordant observation that complication rates and mortality decreased represents the first clear association between CRM training, clinical outcome, and perceived safety climate. To date, no prospective randomized trials evaluating the implementation of CRM are available.

A large nationwide retrospective study, with a contemporaneous control group, in surgical patients reported a decrease in the overall mortality rate in (non-randomized) hospitals that participated in a training program focused on briefings and debriefings in the operating room (including the use of checklists), while no decrease in mortality rate was observed in the control group. In this study, risk-adjusted mortality rates did not reach a statistically significant difference between the trained and non-trained institutes.³⁸

In conclusion, our data indicate an association between CRM implementation and a reduction in complication rate and mortality in critically ill patients as well as an improved perceived safety climate. To our knowledge, this is the first study that links CRM to improved clinical outcome. In view of these results and absence of

deleterious side effects for the patients, one might argue that, similar to aviation, widespread implementation of CRM in the ICU is justified, even without higher levels of evidence obtained from randomized clinical trials.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Data S1. Crew Resource Management training content.

Table S1. Safety Attitudes Questionnaire (SAQ) scores of ICU professionals per discipline.