Graduate thesis

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Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Circulation and Medical Imaging

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Short-term Effects of Endotracheal Suctioning in Post-Cardiac Arrest Patients

Graduate thesis in Medicine, Programme of Professional Study
Supervisor: Pål Klepstad (Prof., MD, PhD)
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Preface

We would like to thank our supervisors Pål Klepstad (Prof., MD, PhD) and Halvor Johannes Breivik Langeland (MD) for their excellent guidance and support during this process. We are also grateful to Dr. Langeland for providing us with all necessary materials from the main study, which made it possible to conduct the present analysis. We also wish to thank Trond Nordseth (MD, PhD) for help with extracting material from the electronical critical management system and for giving us guidance in the conduct of statistical analyses.

Abstract

Introduction: Endotracheal suctioning is required to maintain patent airways but can frequently lead to adverse effects. We studied the incidence and risk factors for such adverse effects in post-cardiac arrest patients. Method: This study was conducted as a planned sub-study of a single-center, prospective observational cohort study. 36 mechanically ventilated adults were followed for a 5-day period after cardiac arrest, collecting data in minute-resolution. For each endotracheal suctioning, data on heart rate, arterial blood pressure, central venous blood pressure, oxygen saturation, fraction of inspired oxygen, respiratory rate, minute ventilation, positive end-expiratory pressure (PEEP) and setting of pressure control over PEEP were collected for 10 minutes before up to 30 minutes after the procedure. The data were analyzed in regard to the occurrence and risk factors for circulatory and/or respiratory deterioration. Results: Circulatory and/or respiratory deterioration occurred frequently in this patient group: oxygen desaturation in 10.3% of suctionings and severe hypotension in 6.6% of suctionings. Cardiovascular Sequential Organ Failure Assessment (SOFA) score, light sedation and oxygen desaturation prior to suctioning were independently associated with increased risk for oxygen desaturation. First intensive care unit (ICU) day, cardiovascular SOFA score, suction with manual ventilation and combined suction and patient repositioning were identified as risk factors for severe hypotension. Conclusions: Endotracheal suctioning frequently leads to deterioration of hemodynamic and/or respiratory parameters in post-cardiac arrest patients. Especially oxygen desaturation and hypotension should be anticipated during endotracheal suctioning in these patients during their first day of ICU care.

Sammendrag

Introduksjon: Endotrakeal suging er en intensivprosedyre som er nødvendig for å opprettholde åpne luftveier, men som ofte kan føre til uheldige fysiologiske effekter. Vi studerte insidensen av og risikofaktorer for slike fysiologiske forverringer hos hjertestanspasienter. Metode: Studien ble gjennomført som en planlagt sub-studie av en prospektiv singel-senter kohort observasjonsstudie. 36 intuberte voksne pasienter ble fulgt i 5 døgn etter gjennomgått hjertestans, hvor minuttsoppløste data ble samlet inn kontinuerlig. For hver endotrakeal sugeprosedyre ble data på hjertefrekvens, arterielt blodtrykk, sentralt venøst blodtrykk, oksygen saturasjon, fraksjon av inspirert oksygen, respirasjonsfrekvens, minuttventilasjon, positivt ende-ekspiratorisk trykk (PEEP) og trykkstøtte over PEEP samlet inn for perioden 10 minutter før inntil 30 minutter etter start av prosedyren. Dataene ble analysert med hensyn til forekomsten av og risikofaktorer for sirkulatorisk og/eller respiratorisk forverring. Resultater: Sirkulatorisk og/eller respiratorisk forverring inntraff hyppig i denne pasientgruppen: oksygen desaturasjon forekom i 10.3% av sugeprosedyrene og alvorlig hypotensjon i 6.6% av sugeprosedyrene. Kardiovaskulær Sequential Organ Failure Assessment (SOFA) score, lett sedasjon og oksygen desaturasjon før sugeprosedyren var uavhengige risikofaktorer for oksygen desaturasjon. Første dag på intensivavdeling, kardiovaskulær SOFA score, endotrakeal suging med manuell ventilasjon og kombinert endotrakeal suging med leieendring ble identifisert som risikofaktorer for alvorlig hypotensjon. Konklusjon: Endotrakeal suging fører hyppig til forverring av hemodynamiske og/eller respiratoriske variabler hos hjertestanspasienter. Spesielt oksygen desaturasjon og hypotensjon burde forventes ved endotrakeal suging hos disse pasientene i løpet av første intensivdøgn etter hjertestans.

Trial registration: ClinicalTrials.gov: NCT02648061

Introduction

Endotracheal suctioning is an important intensive care routine in intubated patients. By mechanically removing accumulated pulmonary secretions, this procedure secures patent airways, and reduces the risk of atelectasis and pulmonary infections (1). However, there are many risks and complications associated with this procedure, such as cardiovascular

instability, hypoxemia, atelectasis, elevated intracranial pressure, infection, bleeding and causing of lesions in the tracheal mucosa (2, 3). According to the 2010 clinical practice guidelines for endotracheal suctioning outlined by the American Association of Respiratory Care (AARC), endotracheal suctioning should therefore only be done when clinically indicated and not routinely (2). The most frequently used indications for endotracheal suctioning are coarse crackles auscultated over the trachea, sawtooth pattern on flow-volume loop on ventilator monitor, coughing and visible secretions in the airway (2, 4). As a result of this, the frequency with which endotracheal suctioning is performed differs between patients, with reported mean values varying from 8 to 17 times per day (5).

Even though clinical guidelines have been compiled to ensure the best practice for endotracheal suctioning, this intervention still needs extensive investigation (6). A high number of studies have been conducted to explore different aspects of endotracheal suctioning, but there is still no consensus for some elements of the procedure. First, many studies have addressed the difference between the use of an open or closed system for endotracheal suctioning, without being able to establish the superiority of either system (3, 5, 7, 8). Only in patients with acute lung injury, guidelines recommend using a closed suction system as this seems to minimize the loss of pulmonary volume and reduce the risk of alveolar collapse (1-3). Second, the depth of catheter insertion is still to be determined (9-11).

Several studies have investigated the effect of endotracheal suctioning on physiologic parameters, showing that endotracheal suctioning in generalized terms tends to lead to an increase in heart rate and mean arterial pressure and a drop in peripheral oxygen saturation (5, 10, 12-14). In a study from 2013, Maggiore et al. found that adverse effects of endotracheal suctioning were frequent, but that the implementation of guidelines was associated with fewer complications. Risk factors independently associated with the occurrence of adverse effects were suctioning frequency and positive end-expiratory pressure (PEEP) > 5 cm H_2O at start of the procedure. Also, they found that oxygen desaturation was a risk factor for hemodynamic alterations during endotracheal suctioning (13).

Most of studies on endotracheal suctioning are done on unselected ICU populations. Furthermore, several studies have excluded patients with hemodynamic instability requiring vasopressors (14-17). Thus, there is a lack of studies investigating the effects of endotracheal suctioning in patient groups who are more vulnerable to changes in circulatory and respiratory

parameters, such as post-cardiac arrest patients. In these patients, hemodynamic instability requiring administration of vasoactive drugs is frequent (18). The aim of this study is to describe the short-time effects of endotracheal suctioning on hemodynamic and respiratory parameters in post-cardiac arrest patients and, if possible, to identify risk factors in this patient group for deterioration in hemodynamic and/or respiratory parameters after endotracheal suctioning.

Methods

Study Design

This is a planned sub-study of a single-center, prospective, observational cohort study of 50 patients admitted to St. Olav's University Hospital after out-of-hospital cardiac arrest (OHCA), between January 2016 to November 2017 (19). Out of these 50 patients, we have in the present analysis included only patients who were mechanically ventilated, and with at least one included endotracheal suctioning procedure during the five days follow-up period.

The study was approved by the Regional Committee for Medical and Health Research Ethics, Central Norway Health Region (REK Midt, No. 2015/1807). Written informed consent was obtained from either the patient, or next-of-kin if the patient was unable to consent, in all cases.

Setting

All data are gathered at the intensive care unit (ICU) and coronary care unit (CCU) at St. Olav's University Hospital, a tertiary university hospital in Trondheim (Norway), with a catchment population of 700,000.

Eligibility

All adult patients who were admitted to either the ICU or the CCU at St. Olav's University Hospital with obtained return of spontaneous circulation (ROSC) after OHCA were considered for inclusion. Inclusion was performed immediately after arrival to the ICU or CCU. Exclusion criteria were age < 18 years, cardiac arrest (CA) of anaphylactic or septic origin, sepsis within 24 hours before CA, pregnant women, patients transferred from other

hospitals after OHCA, and decision to withdraw or withhold life sustaining therapy after hospital arrival. Patients were later included in the present analysis if they were mechanically ventilated and had at least one registered endotracheal suctioning procedure.

If patients were excluded from further follow-up in the main study, the reason for drop-out was recorded and all data obtained until drop-out are included in the present analysis. Reasons for drop-out of the study were acute cardiothoracic surgery or intervention with ventricular assist device or extracorporeal membranous oxygenation support, death, decision to withdraw life-sustaining therapy, and transfer of the patient to a general ward or another hospital.

Study procedure

Endotracheal suction was performed on intubated patients to secure patent airways when indicated, following the local procedure-specific guidelines. The prevailing guidelines were largely based on the 2010 AARC clinical practice guidelines for endotracheal suctioning (2). Indications for endotracheal suctioning were sounds from the respiratory tract indicating sputum, visual sputum in the tube, coarse crackles over the trachea, reduced ability to generate an effective cough, decreased tidal volume during pressure-controlled mechanical ventilation, increased peak inspiratory pressure during volume-controlled mechanical ventilation, fall in oxygen saturation and/or deteriorating blood gas values, suspected aspiration or the need to obtain a sputum specimen for microbiological diagnostics. Depending on the endotracheal tube size, a 10, 12, or 14 French scale catheter was used to perform the procedure through either a closed suction system or an open suction system. The duration of the suctioning was 5-15 s with catheter withdrawal and with the minimum negative pressure needed (≤ 150 mmHg). When indicated (e.g. the patient had an oxygen desaturation of clinical importance), mechanical pre-oxygenation with 100% oxygen was given for 1 minute. Post-oxygenation was considered if the patient showed a significant oxygen desaturation after the procedure. When deemed necessary, endotracheal suction with an open suction system was combined with manual ventilation. During the study period the nursing staff recorded the exact time, at which the procedures were initiated, and the duration. It was also recorded whether the suctioning procedure was done with or without manual ventilation.

Data collection

During the study period, data on vital variables and respiratory support were registered in the hospitals electronic critical care management system (Picis CareSuite, Optum Inc., USA). All patients had invasive blood pressure monitoring via intra-arterial cannula and central venous blood pressure monitoring via either a central venous catheter (CVC) or a Swan-Ganz pulmonary artery catheter (PAC). In the study, the ICU day was defined from 6 AM until 6 AM the following day. Day one in the study was defined from tine of arrival to 6 AM the following morning, thus day one had different duration between patients. A more detailed description of the general protocol and the post-cardiac arrest care is published previously (19).

At time of inclusion the following baseline variables were registered: patient characteristics: age, sex, height, weight; Charlson Comorbidity Index (CCI) (20); Simplified Acute Physiology Score II (SAPSII) (21); characteristics related to the cardiac arrest and prehospital treatment (Utstein Style Template) (22): location, witnessed arrest, bystander cardiopulmonary resuscitation (bystander CPR), time to basic life support, initial monitored rhythm, time to defibrillation, time to ROSC, presumed etiology, known pulmonary aspiration during CPR, and whether the patient was in a circulatory shock when admitted. Shock was defined as systolic blood pressure < 90 mmHg or need of circulatory support (fluids and/or vasopressors) to maintain a systolic blood pressure > 90, and/or signs of end-organ hypoperfusion (23, 24).

After inclusion, the following variables were recorded and registered every minute in the electronic ICU chart, Picis Critical Care Manager (Optum Inc, USA): heart rate; invasive arterial blood pressure; central venous blood pressure (CVP); peripheral transcutaneous oxygen saturation (SpO_2); respiratory rate; fraction of inspired oxygen (FiO_2); minute ventilation (MV); positive end-expiratory pressure (PEEP); setting of Pressure Control over PEEP (SetPC). For the calculations in the descriptive analysis, the baseline value for the recorded variables was defined as the mean value during the preceding 5 to 10 minutes.

From the electronic critical care management system (Picis CareSuite, Optum Inc., USA) the following information about every procedure reported was extracted: date and time of initiation and duration of each endotracheal suctioning; whether manual ventilation was used during the procedure; other interventions in the time interval from 10 minutes prior until 30

minutes after the initiation of the procedure, such as patient repositioning or extubation; daily Clinical Pulmonary Infection Score (CPIS) (25); daily Sequential Organ Failure Assessment (SOFA) score (26); the nearest reported Richmond Agitation-Sedation Scale (RASS) value (27). Until April 2017 The Motor Activity Assessment Scale (MAAS) was used in the ICU and CCU. For procedures prior to April 2017 the reported MAAS value was changed into the corresponding RASS value. When two adjoining RASS or MAAS values were reported at the same time, the highest value was chosen. The date and time for the initiation of each endotracheal suctioning was then used to extract the recorded respiratory and circulatory variables from 10 minutes prior and to 30 minutes after the procedure. As different patients had endotracheal suctioning done several times during their stay at the ICU/CCU, every endotracheal suctioning procedure was treated as an isolated event.

Exclusion of procedures and censoring data

During the stay at the ICU or CCU, interventions and other clinical events can alter both respiratory and circulatory variables. To account for this, major interventions that occurred within 10 minutes before until 10 minutes after the endotracheal suctioning procedures led to exclusion of the procedure. Such interventions included airway manipulation with bronchoscopy or laryngoscopy, changing of the respiratory tube, extubation of the patient, placement of a nasogastric tube, cardioversion or additional endotracheal suctioning. Procedures where endotracheal suctioning had been performed within 30 minutes prior to the current procedure were also excluded. If any major event occurred after 10 minutes from start of the procedure, the data from after the event were censored. Minor, unimportant events (e.g. blood draws from existing arterial lines, administration of intravenous medications and presence of family, nurse or physician in the room) did not result in exclusion of the procedure or censoring of data. Other reasons for excluding procedures included: inaccurate manual recording of the time of initiation of the procedures; inaccurate manual recording of the time of major events; unreliable manual recording of the length of the procedure; technical issues in recording of the data.

Patient repositioning is often done simultaneously with endotracheal suctioning. These procedures were registered as combined procedures. If position change occurred after 10 minutes from start of the procedure, the data were censored from the start of the event. Figure 1 shows a timeline summarizing events leading to exclusion or censoring of data.

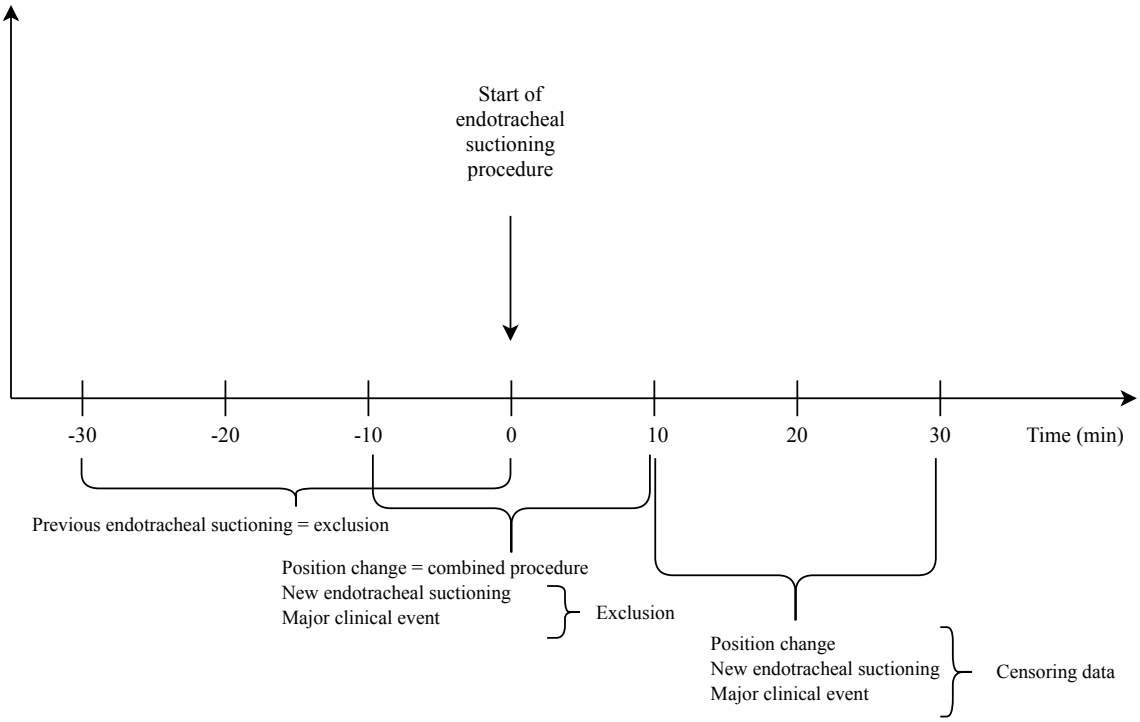

Figure 1. Timeline summarizing exclusion of procedures and events leading to censoring of data.

Statistics and data analysis

Demographic data are shown using median and interquartile range (IQR) or range. The main outcome for the study was circulatory or respiratory deterioration within 15 minutes after initiation of endotracheal suctioning. Respiratory deterioration was defined as oxygen desaturation (SpO_2 < 85%), and circulatory deterioration was defined as one or more of the following: tachycardia (heart rate > 120 beats per minute), severe hypertension (systolic blood pressure > 200 mmHg) and severe hypotension (systolic blood pressure < 80 mmHg). For the predictive analyses, only oxygen desaturation and severe hypotension was used as outcome.

Logistic regression analysis was performed to identify risk factors predicting respiratory and/or circulatory deterioration. In the analysis, procedure-specific variables were chosen as covariates, due to that the same patients had several procedures. Procedure-specific variables that were considered as possible independent covariates were: ICU day, SOFA score, CPIS, level of sedation, suction with manual ventilation, combined suction and patient repositioning, frequency of suctioning, FiO_2 level and baseline oxygen desaturation prior to suctioning. Univariate logistic regression analysis was conducted comparing suctioning procedure-specific variables with the outcome. Multivariate logistic regression analysis was then

conducted incorporating factors with $P < 0.20$ in the univariate analysis. Factors with clear interaction potential with other covariates in the multivariate analysis were left out despite having $P < 0.20$ in the univariate analysis. Results are expressed as odds ratio (OR) and 95% confidence intervals. A P value < 0.05 was considered statistically significant. Concordance statistics (C-statistics) were used to determine the goodness of fit. All analyses were performed using R Statistical software version 3.6.1 (© R Foundation for Statistical Computing, 2016).

As the data collected contained variables that were automatically registered by the hospitals electronic critical care management system, there were possibilities for erroneous registrations. Necessary clinical interventions such as blood draws from, and flushing of, the intra-arterial cannula are examples of causes that led to false registrations. To correct for such errors, the set of data was filtered to only include values within a range considered clinically probable. All values that were lower or higher than these minimum or maximum values were changed to missing values. Table 1 shows the minimum and maximum values chosen for each variable.

Table 1. Minimum and maximum cut-off values for physiological variables

Variable	Min	Max
Heart rate (bpm)	30	250
Systolic BP (mmHg)	40	250
Diastolic BP (mmHg)	20	150
Mean Arterial Pressure (mmHg)	20	150
Central Venous Pressure (mmHg)	0	40
SpO_2 (%)	55	100
FiO_2 (%)	21	100
PEEP (cm H_2O)	0	20
SetPC (cm H_2O)	6	40
Respiratory rate (breaths/min)	5	40
Respiratory MV (L/min)	0.3	15

bpm = Beats per minute
BP = Blood pressure
SpO_2 = Peripheral transcutaneous oxygen saturation
FiO_2 = Fraction of inspired oxygen
PEEP = Positive End-Expiratory Pressure
SetPC = Setting of Pressure Control over PEEP
MV = Minute volume

Table 1. Minimum and maximum cut-off values for different physiological variables used for filtration of data for erroneous registrations.

Results

Demographics

Initially 38 patients out of the 50 patients in the main study were included in this analysis. Out of these, additionally 2 patients were excluded as they only had endotracheal suctioning procedures done that were excluded due to various reasons. In total, there were 36 patients included in the present analysis (figure 2).

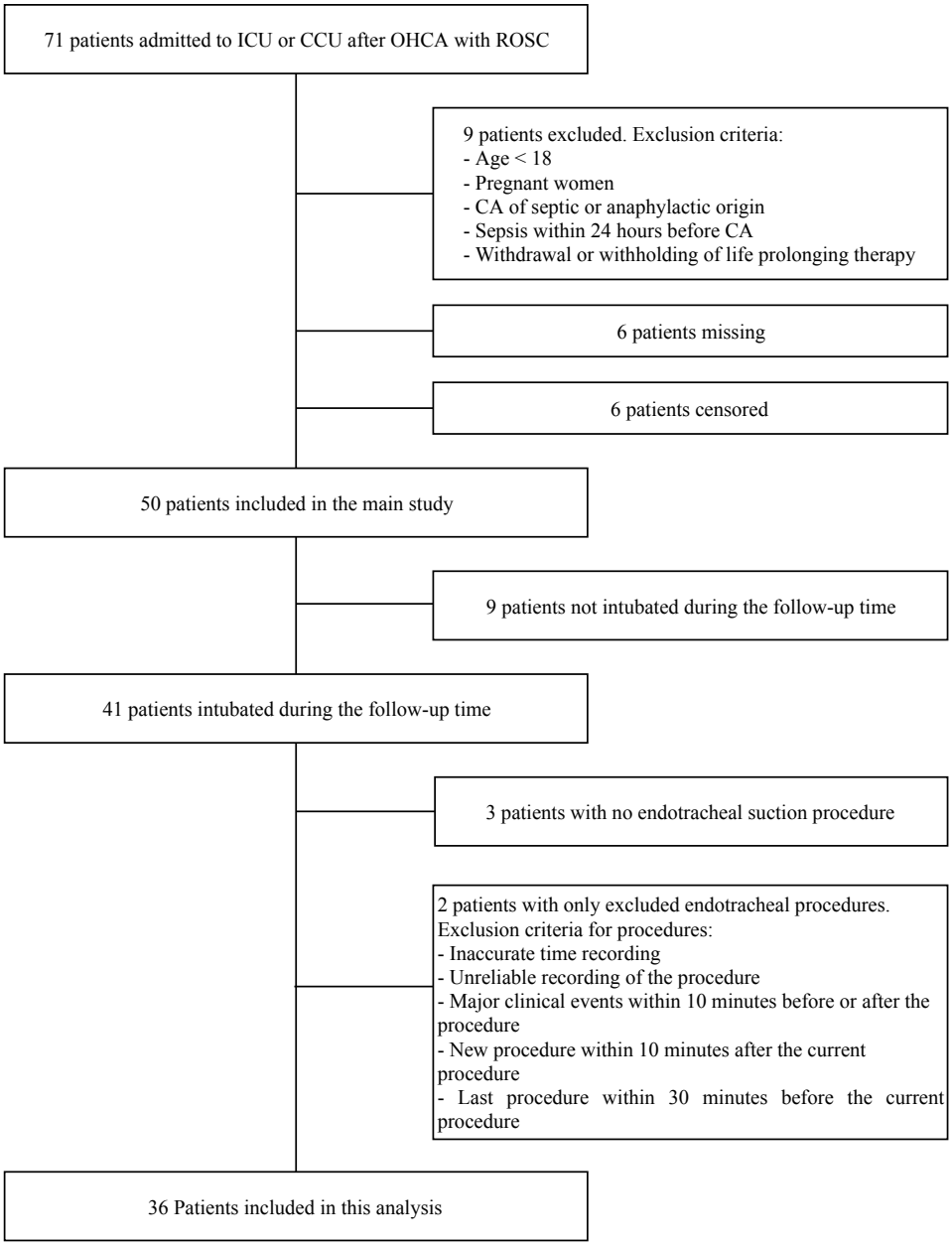

Figure 2. Flowchart summarizing patient enrollment. CCU: coronary care unit; ICU: intensive care unit; OHCA: out-of-hospital cardiac arrest; ROSC: return of spontaneous circulation; CA: cardiac arrest.

The median age was 67.5 (IQR 59.3 − 76.0) years, and 31 (86%) patients were male. The cause of OHCA was cardiac in 32 (89%) patients and asphyxia in 3 (8%) patients. OHCA was witnessed in 30 (83%) patients, 32 (89%) patients received bystander CPR and the median time to ROSC was 25.5 (IQR 19 − 33) minutes. Additional patient characteristics are presented in table 2.

Table 2. Patient characteristics and demographic data

Patients observed, n	36
Male, n (%)	31 (86)
Age (y), median (IQR)	67.5 (59.3 – 76.0)
BMI (kg/m^2), median (IQR)	26.7 (24.9 – 30.9)
Charlson Comorbidity Index, median (IQR)	3.5 (2.0 – 4.3)
Location of cardiac arrest, n (%)	
Home	12 (33)
Public	15 (42)
Other	9 (25)
Witnessed cardiac arrest, n (%)	30 (83)
Bystander CPR, n (%)	32 (89)
Time to basic life support (minutes), median (IQR)	1 (1 – 2)
Time to defibrillation (minutes), median (IQR)	11 (5 – 14)
Time to ROSC (minutes), median (IQR)	25.5 (19 – 33)
Cause of cardiac arrest, n (%):	
Cardiac	32 (89)
Asphyxia	3 (8)
Other	1 (3)
Initial monitored rhythm, n (%)	
Asystole	1 (3)
Ventricular fibrillation	28 (78)
PEA	6 (17)
Other	1 (3)
Certain pulmonary aspiration, n (%)	9 (25)
Shock, n (%)	14 (39)
SAPS II, median (IQR)	67.5 (58.8 – 75.0)
Number of suctions/patient, median (range)	13 (1 – 33)

IQR = Interquartile range
BMI = Body Mass Index
CPR = Cardiopulmonary resuscitation
ROSC = Return of spontaneous circulation
PEA = Pulseless electrical activity
SAPS II = Simplified Acute Physiology Score II

During the follow-up period, 15 patients dropped out of the study before day 5. Reasons for drop-out were death (n=8), transfer to a general ward (n=6) and acute cardiothoracic surgery (n=1). During the follow-up time, each patient contributed with a median study-time of 112.5 (range 11.4 − 142.6) hours and had a median of 13 (range 1 − 33) included suction procedures.

From the 38 patients initially included, there were 600 registered endotracheal suctioning procedures. 163 procedures were excluded due to inaccurate recording of the procedure or concomitant other events (n = 89), technical issues in recording the data (n = 37), endotracheal suctioning procedures done at short intervals (n = 28), manipulation of the airways (n = 4) and other major clinical events (n = 5). Out of the remaining 437 procedures, 171 were recorded as combined procedures with position change and 56 were done with manual ventilation. A total of 46 events were censored.

Table 3 shows the characteristics related to each of the procedures. For the calculation of *Number of suctions/patient/day* and *> 6 suctions/day* both included and excluded suctioning procedures have been taken into account. The median length of the first ICU-day was 13 (range 1 − 20) hours.

Clinical changes after the suction procedures

During the follow-up time, respiratory and/or circulatory deterioration occurred in 90 (20.6%) procedures and in 28 (77.8%) patients. Respiratory deterioration occurred after endotracheal suctioning in 10.3% of the procedures and in 69.4% of subjects. Circulatory deterioration occurred in 13.3% of the procedures and in 61.1% of subjects; tachycardia occurred in 4.1% of the procedures and in 19.4% of subjects, hypertension occurred in 3.0% of procedures and in 19.4% of subjects and hypotension occurred in 6.6% of procedures and in 41.7% of subjects. Figure 3 and figure 4 show the mean values for the circulatory and respiratory variables, respectively, shown as changes from the baseline values for each event. Figure 5 and 6 show stacked bar plots of all measured values of systolic blood pressure, CVP, heart rate, SpO_2 and respiratory MV.

Table 3. Procedure characteristics

Procedures included in study, n	437
ICU day 0†, n (%)	19 (4)
ICU day 1, n (%)	58 (13)
ICU day 2, n (%)	101 (23)
ICU day 3, n (%)	108 (25)
ICU day 4, n (%)	93 (21)
ICU day 5, n (%)	58 (13)
SOFA total, median (IQR)	11 (9 – 12)
SOFA respiration, median (IQR)	3 (2 – 3)
SOFA cardiovascular, median (IQR)	3 (1 – 4)
Light sedation (RASS -2 – 6), n (%)	26 (6)
Moderate sedation (RASS -3), n (%)	115 (26)
Deep sedation (RASS -5 - -4), n (%)	292 (67)
CPIS, median (IQR)	6 (4 – 7)
Baseline oxygen desaturation††, n (%)	41 (9)
Number of suctions/patient/day, median (range)	6 (1 – 14)
> 6 suctions/day, n (%)	179 (41)
FiO_2‡ > 60%, n (%)	13 (3)
PEEP‡ (cm H_2O), median (IQR)	8.2 (7.8 – 10.0)
SetPC‡ (cm H_2O), median (IQR)	14 (12 – 16)
Suction with manual ventilation, n (%)	56 (13)
Combined suction and patient repositioning, n (%)	171 (39)

† The median length of first ICU day was 13 (range 1 – 20) hours
†† Mean value of SpO_2 < 92% during t = -10 to t = -5
‡ Values measured at t = -10
IQR = Interquartile range
SOFA = Sequential Organ Failure Assessment
RASS = Richmond Agitation-Sedation Scale
CPIS = Clinical Pulmonary Infection Score
FiO_2 = Fraction of inspired oxygen
PEEP = Positive End-Expiratory Pressure
SetPC = Setting of Pressure Control above PEEP

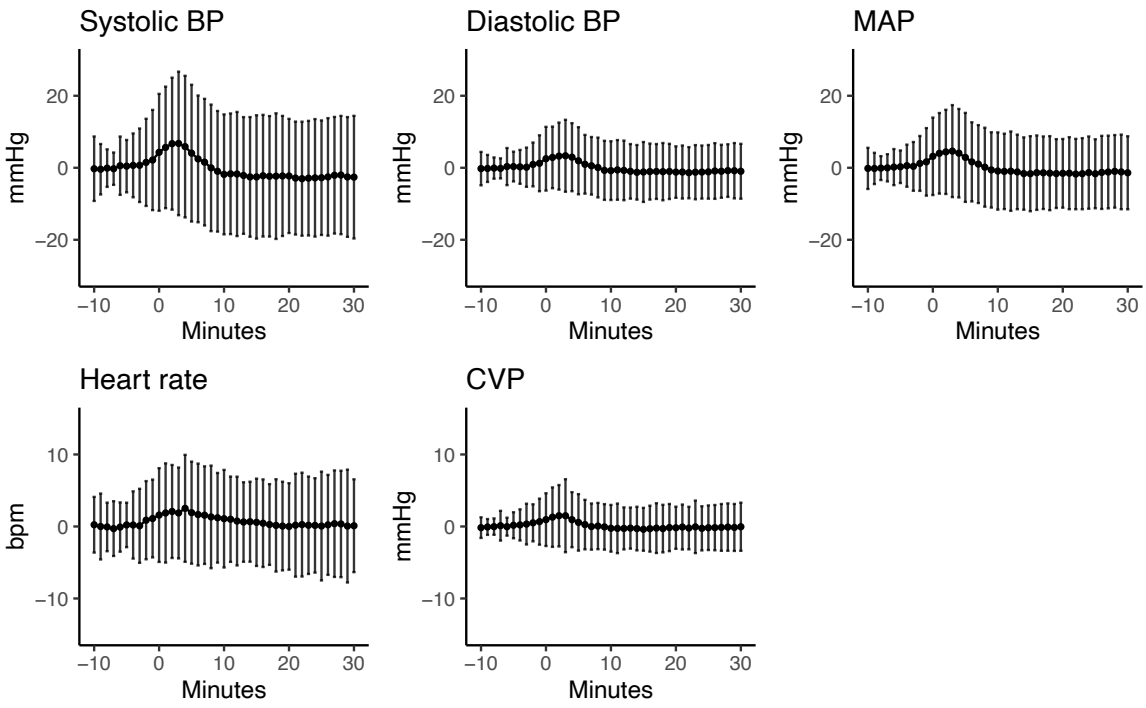

Figure 3. Mean values shown as change from the baseline values of circulatory variables. The bars represent the standard deviations (± SD) from the mean and time = 0 marks the initiation of the endotracheal suctioning procedure. Baseline value is the mean value during t=-10 to t=-5. BP: Blood pressure; MAP: Mean arterial pressure; CVP: Central venous pressure

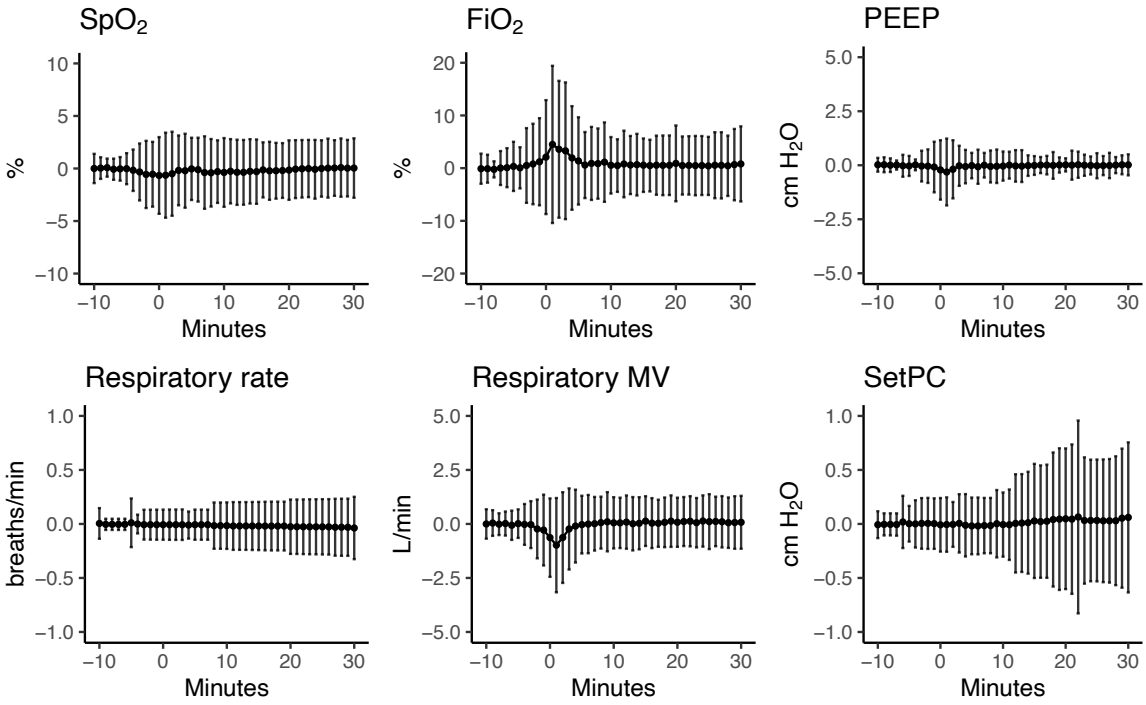

Figure 4. Mean values shown as change from the baseline values of respiratory variables. The bars represent the standard deviations (± SD) from the mean and time = 0 marks the initiation of the endotracheal suctioning procedure. Baseline value is the mean value during t = -10 to t = -5. SpO_2: Peripheral transcutaneous oxygen saturation; FiO_2: Fraction of inspired oxygen; PEEP: Positive End-Expiratory Pressure; MV: Minute volume; SetPC: Setting of Pressure Control above PEEP.

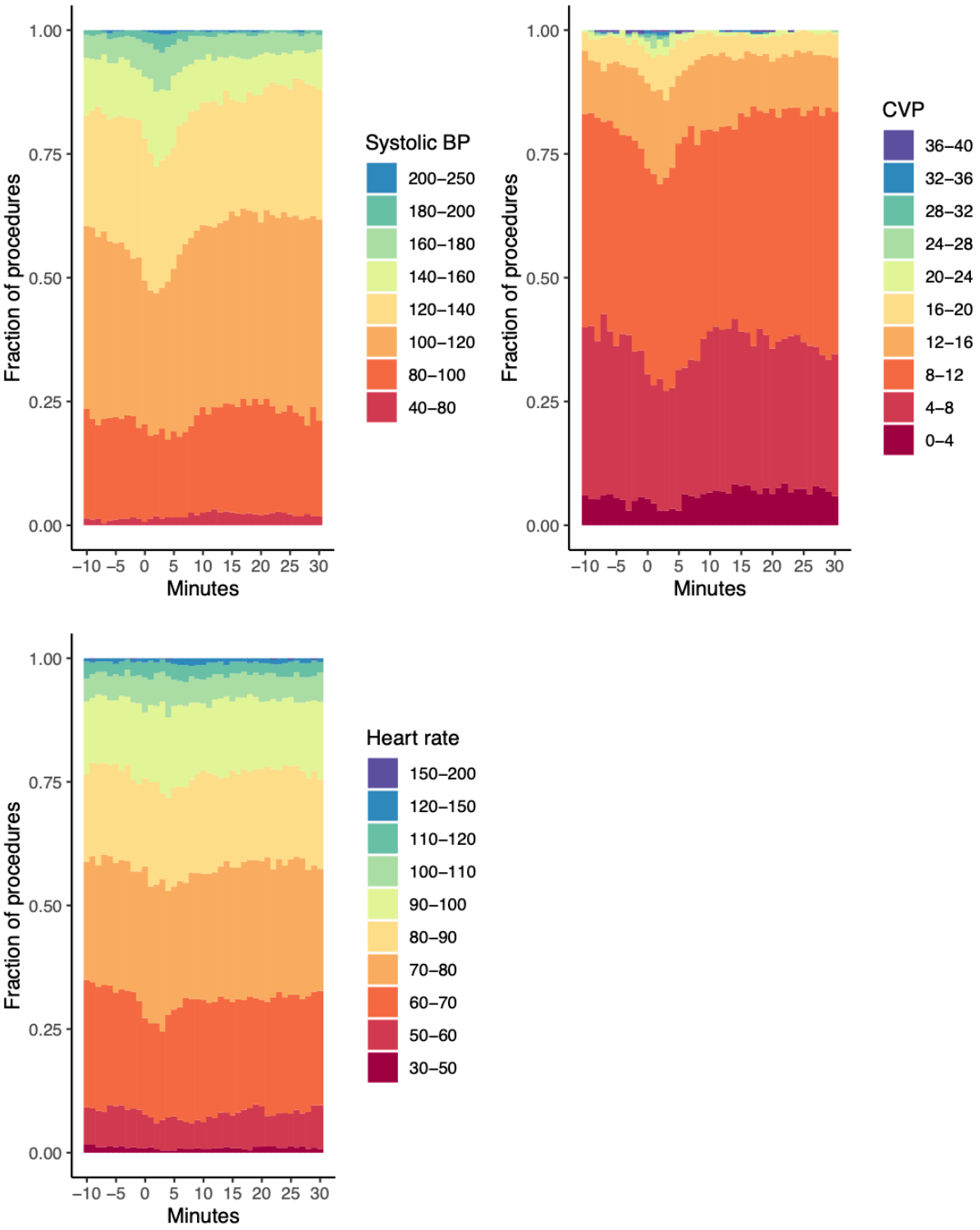

Figure 5. Stacked bar plots showing all measured values, time = 0 marks the initiation of the endotracheal suctioning procedure. BP: Blood pressure; CVP: Central venous pressure.

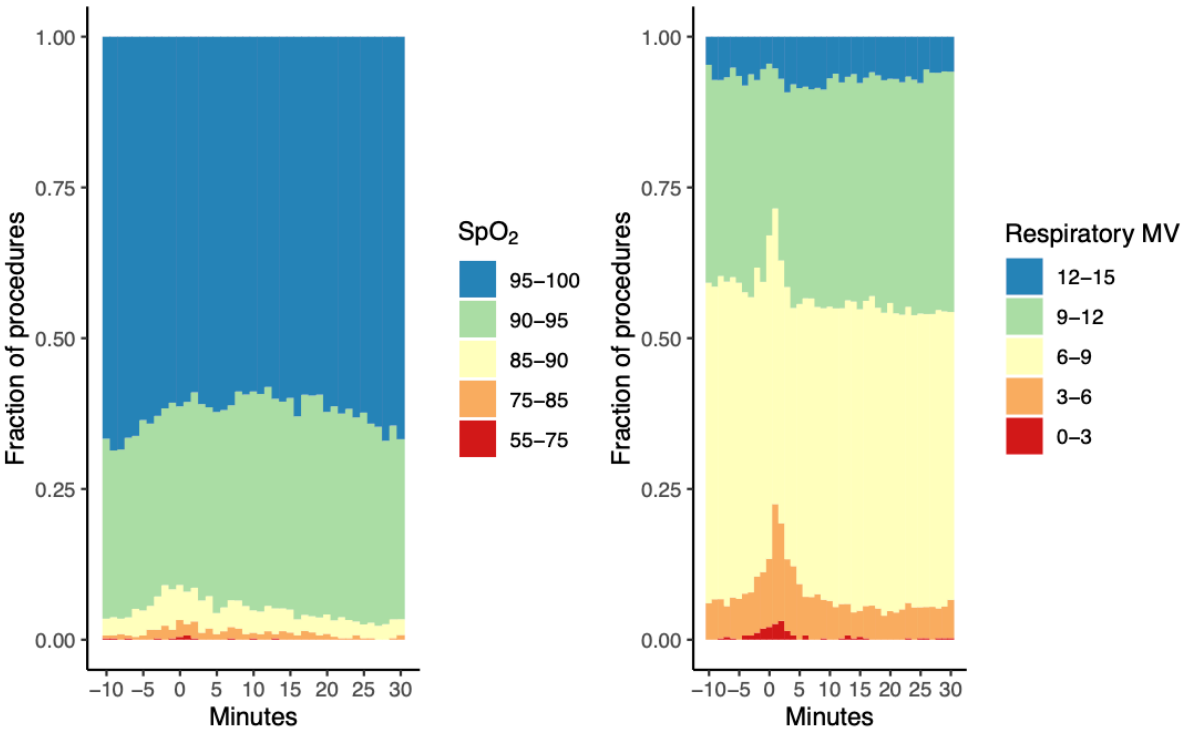

Figure 6. Stacked bar plots showing all measured values, time = 0 marks the initiation of the endotracheal suctioning procedure. SpO_2: Peripheral transcutaneous oxygen saturation; MV: Minute volume.

Predictive analysis for clinical deterioration

For the predictive analysis, the dependent outcome was oxygen desaturation (SpO_2 < 85%) and severe hypotension (systolic blood pressure < 80 mmHg). Cardiovascular SOFA-score, light sedation (RASS -2 to 6) and baseline oxygen desaturation (SpO_2 < 92%) prior to suctioning were independently associated with an increased risk of oxygen desaturation during endotracheal suctioning (table 4). The model's ability to discriminate was moderate; C-statistic 0.77. For severe hypotension during endotracheal suctioning, independently associated risk factors were ICU day 0, cardiovascular SOFA-score, suction with manual ventilation and combined suction and patient repositioning (table 4). The discriminative ability of this model was strong; C-statistic 0.81. For each increase in cardiovascular SOFA-score, the odds for oxygen desaturation increased with 83%, whereas the odds for severe hypotension increased with 80%.

Table 4. Univariate and Multivariate Logistic Regression Analysis of Complications of Endotracheal Suctioning

	Univariate analysis			Multivariate analysis		
	Odds Ratio	95% CI	*P*	Odds Ratio	95% CI	*P*
Oxygen desaturation (SpO_2 < 85)						
ICU day 0†	4.49	1.51 – 12.05	0.004	3.09	0.74 – 11.39	0.102
ICU day 1	1.75	0.75 – 3.72	0.165	0.79	0.27 – 2.11	0.647
ICU day 2	0.82	0.36 – 1.69	0.602			
ICU day 3	0.63	0.27 – 1.34	0.258			
ICU day 4	0.78	0.33 – 1.66	0.545			
ICU day 5	0.80	0.27 – 1.95	0.652			
SOFA total	1.18	1.03 – 1.36	0.018			
SOFA respiration	1.83	1.17 – 2.96	0.011			
SOFA cardiovascular	1.73	1.28 – 2.50	0.001	1.83	1.26 – 2.91	**0.004**
CPIS	0.97	0.84 – 1.12	0.636			
Light sedation (RASS -2 – 6)	2.31	0.74 – 6.06	0.111	4.46	1.27 – 13.80	**0.012**
Moderate sedation (RASS -3)	0.60	0.25 – 1.28	0.217			
Deep sedation (RASS -5 – -4)	1.13	0.58 – 2.30	0.731			
Suction with manual ventilation	1.84	0.79 – 3.91	0.133	2.27	0.92 – 5.23	0.063
Combined suction and patient repositioning	1.90	1.02 – 3.57	0.042	1.74	0.87 – 3.51	0.117
> 6 suctions/day	0.49	0.24 – 0.95	0.043	0.82	0.35 – 1.88	0.651
FiO_2‡ > 60%	4.23	1.11 – 13.65	0.021	1.66	0.29 – 7.63	0.539
Baseline oxygen desaturation††	4.01	1.78 – 8.56	<0.001	3.86	1.52 – 9.33	**0.003**
Hypotension (Systolic BP < 80)						
ICU day 0†	7.93	2.59 – 22.11	<0.001	5.17	1.31 – 18.29	**0.013**
ICU day 1	1.40	0.45 – 3.54	0.516			
ICU day 2	0.86	0.31 – 2.05	0.749			
ICU day 3	0.47	0.14 – 1.24	0.167	0.61	0.17 – 1.75	0.399
ICU day 4	0.96	0.35 – 2.30	0.936			
ICU day 5	0.47	0.07 – 1.61	0.306			
SOFA total	1.30	1.09 – 1.57	0.005			
SOFA respiration	2.12	1.21 – 3.87	0.012			
SOFA cardiovascular	2.06	1.35 – 3.61	0.004	1.80	1.18 – 3.17	**0.017**
CPIS	1.14	0.95 – 1.38	0.177	1.10	0.90 – 1.37	0.357
Light sedation (RASS -2 – 6)	0.56	0.03 – 2.82	0.580			
Moderate sedation (RASS -3)	1.11	0.45 – 2.52	0.803			
Deep sedation (RASS -5 – -4)	1.02	0.46 – 2.43	0.961			
Suction with manual ventilation	2.86	1.14 – 6.59	0.018	3.47	1.31 – 8.65	**0.009**
Combined suction and patient repositioning	2.34	1.09 – 5.14	0.030	2.31	1.03 – 5.41	**0.046**
> 6 suctions/day	0.63	0.27 – 1.38	0.264			
FiO_2‡ > 60%	7.04	1.81 – 23.31	0.002	2.34	0.41 – 10.79	0.298
Baseline oxygen desaturation††	2.14	0.69 – 5.55	0.144	1.47	0.40 – 4.39	0.525

† The median length of first ICU day was 13 (range 1 – 20) hours
†† Mean value of SpO_2 < 92% during t = -10 to t = -5
‡ Values measured at t = -10
ICU = Intensive Care Unit
SOFA = Sequential Organ Failure Assessment
CPIS = Clinical Pulmonary Infection Score
RASS = Richmond Agitation-Sedation Scale
FiO_2 = Fraction of inspired oxygen
SpO_2 = Peripheral transcutaneous oxygen saturation
BP = Blood pressure

Discussion

The main results of this study are that:

- Endotracheal suctioning was frequently complicated by adverse effects, mainly by oxygen desaturation and hypotension.
- Mean respiratory and circulatory deteriorations were minor, and most changes returned to baseline within 10 minutes
- Cardiovascular SOFA-score, light sedation and baseline desaturation prior to suctioning were independent risk factors for oxygen desaturation
- First ICU day, cardiovascular SOFA-score, suction with manual ventilation and combined suction and patient repositioning were independent risk factors for severe hypotension during endotracheal suctioning

Previous clinical studies have addressed physiological alterations after endotracheal suctioning. In a general population of ventilated ICU-patients, Maggiore et al found that complications of endotracheal suctioning occurred in 12.4% of procedures before the implementation of guidelines but was reduced to 4.9% of procedures after implementation of guidelines (13). In our study, we found a larger incidence of oxygen desaturation and severe hypotension than previously reported (11, 13), but a smaller incidence of hypertension compared with what Van der Leur found in a population of mostly surgical patients without acute respiratory distress syndrome (11). Differences in the definition of adverse effects, in suctioning techniques, patient population and sample size might explain these discrepancies.

Instead of relative changes, we used in the analyses of frequencies and predictive factors absolute cutoff values for blood pressure, heart rate modifications and oxygen desaturation. As shown in the results the risk for an adverse event is an interplay between factors related to the patients' general condition and the actual suction procedure. Thus, the risk for an event being categorized as complicated would be higher for patients with baseline values close to the defined cut-off values. However, for the patient it is the clinical deterioration that is of interest, not the magnitude of change.

As shown in figure 3 and figure 4, endotracheal suctioning resulted in changes in both circulatory and respiratory variables. For most of the circulatory variables, the mean changes returned to baseline within 10 minutes. The changes did however last longer than what is reported in earlier studies (12, 14). Only in a study by Bourgault et al, systolic blood pressure changes remained elevated over pre-suctioning levels even after 10 minutes (28). Respirator settings such as respiratory rate and SetPC varied little around t = 0, which shows that few adjustments of respirator settings were done during endotracheal suctioning. Both PEEP and respiratory minute volume decreased at time of initiation of the procedure but returned to baseline after less than 5 minutes. FiO_2 was increased and varied between patients at t = 0. This can be explained by the hyperoxygenation (FiO_2 = 100%) given prior to and/or after some of the procedures. Also, hyperoxygenation may have impacted SpO_2 for the same procedures.

As shown in figure 5, systolic blood pressure, CVP and heart rate increased at the initiation of endotracheal suctioning. Still, most measured values remained within the normal range. The stacked bar plot for systolic blood pressure shows that a larger fraction of the procedures was associated with a low systolic blood pressure < 80 mmHg after initiation of endotracheal suctioning (t = 0) compared to before the suctioning. Many of these procedures also remain low in blood pressure for 30 minutes after the endotracheal suctioning. In the stacked bar plot with measured values for SpO_2 (figure 6), the saturation seems to decrease already before initiation of the procedure, and the changes last somewhat longer compared to the circulatory variables. This premature decrease in peripheral oxygen saturation might be explained by prior events leading to desaturation, which can also be the indication for why endotracheal suctioning was initiated in the first place.

In the study by Maggiore et al. assessing risk factors for adverse effects of endotracheal suctioning, PEEP > 5 cm H_2O and > 6 suctionings/day were identified as independent risk factors for oxygen desaturation. Oxygen desaturation was the only identified risk factor for blood pressure changes (13). In our study, there was no connection between > 6 suctionings/day and an increased risk for oxygen desaturation after endotracheal suctioning. Maggiore et al. finding PEEP > 5 as a risk factor was not possible to compare in our analysis as standard PEEP applied for all patients was 8 or above.

In our study, cardiovascular SOFA-score was independently associated with both oxygen

desaturation (OR = 1.83, *P* = 0.004) and severe hypotension (OR = 1.80, *P* = 0.017). The cardiovascular SOFA-score gives an impression of how hemodynamically unstable the patient is, and whether a large or small dose of vasopressors is needed to maintain a satisfying mean arterial pressure (29). Thus, there seems to be a connection between adverse effects from endotracheal suctioning and increased hemodynamic instability. In our results, the first ICU day (ICU day 0) was the strongest independent predictor for severe hypotension during endotracheal suctioning (OR = 5.17, *P* = 0.013). This also might be connected to hemodynamic instability being more pronounced in the first hours after CA. In a study from 2002, Laurent et al found that severe myocardial dysfunction can occur after cardiac arrest, independent of severe underlying coronary disease. They suggested that the hemodynamic profile of their findings in post-cardiac arrest patients could be explained with myocardial stunning and increased vasodilatation following cardiac arrest (18). We also found that both suction with manual ventilation (OR = 3.47, *P* = 0.009) and combined suction and patient repositioning (OR = 2.31, *P* = 0.046) was independently associated with severe hypotension, indicating that such procedures represent a greater strain on the patient. However, it should also be taken into account that these interventions might have been undertaken as a result of the patient being more ill. Thus, it is difficult to interpret whether the hypotension is a result of the interventions, or if the intervention is a result of circulatory deterioration.

Light sedation (RASS value between -2 to 6) was the strongest independent predictor for oxygen desaturation (OR = 4.46, *P* = 0.012). In a study on physiologic impacts of closed endotracheal suctioning on spontaneously breathing patients on mechanical ventilation, Seymour et al found that their cohort of patients had larger and longer changes of physiological variables compared with earlier studies on more heavily sedated patients (14). They suggested that deep sedation depresses both laryngeal and tracheal reflexes, and thus blunt the physiologic effect of airway manipulation. This could possibly explain the findings in this analysis, which suggests that less sedated patients are more vulnerable to changes in physiological variables when suctioned.

Baseline oxygen saturation (SpO_2 < 92%) was also a strong independent predictor for oxygen desaturation after endotracheal suctioning (OR = 3.86, *P* = 0.003). This is expected, as it is likely that patients that have a lower saturation prior to the procedure will be more likely to experience a drop in SpO_2 to < 85%. However, as we have used an absolute value to define the outcome for oxygen desaturation, it is also possible that patients have had a SpO_2 of <

85% prior to, under and after endotracheal suctioning. In such cases, it is less likely that the oxygen desaturation is a result of the suctioning procedure.

In existing literature on endotracheal suctioning, many studies have compared adverse effects when using open versus closed suctioning systems. As the guidelines at the St. Olav's University Hospital regard these two systems as equally safe, it is up to the clinical judgement of nurses and other health care professionals to decide which system is to be used at different times. Thus, our analyses cannot assess whether open or closed suction is to be preferred. In an earlier meta-analysis, Favretto et al came to the conclusion that closed endotracheal suctioning leads to less prominent hemodynamical changes in intubated patients compared to open endotracheal suctioning (6). Özden et al came to the same conclusion in their study examining the effects of open and closed suctioning systems on hemodynamic parameters in patients undergoing open heart surgery (30). It would be interesting to see if this also would be the case in a comparison-study between the two systems with only post-cardiac arrest patients.

Strengths and limitations

As far as we know, this is the only study that explores respiratory and circulatory changes after endotracheal suctioning in post-cardiac arrest patients. It is also one of few studies trying to identify risk factors associated with adverse effects after endotracheal suctioning. Moreover, all variables were obtained with an electronic patient chart that automatically obtained all variables at a one-minute interval. The study was also performed at one center, securing that other treatment after CA was standardized.

We recognize also some possible limitations. First, a potential confounder in this study is that each endotracheal suctioning procedure was treated as an isolated event. Patients that were ventilated over a longer time span, or had endotracheal suctioning done more frequently, contributed with a larger number of observations in the study. If these patients were more or less vulnerable to circulatory and respiratory deterioration after endotracheal suctioning, compared to patients with fewer procedures, this will have had an impact on the results. Second, as this study is a single-center study there are limitations considering generalization of the findings of the study. Third, this analysis only investigates the short-time effect of endotracheal suctioning and cannot be used to assess the long-term effects of the procedure in post-cardiac arrest patients. Fourth, this study has no comparison with a different

patient cohort, such as ICU patients without cardiac arrest or patients who were hemodynamically stable. Such a comparison could have strengthened our study in terms of whether our cohort of post-cardiac arrest patients really are more vulnerable to endotracheal suctioning compared to other patients. Finally, endotracheal suctioning is a manually performed procedure. Thus, our study design relies on compliance by the health care workers at the units to follow the current guidelines at the hospital when conducting the procedure. The time for initiation of the procedures was also registered manually by the nurses, which leaves some insecurity in regard to whether the time of initiation (t = 0) for the procedures was registered correctly in all cases.

Conclusion

Endotracheal suctioning in post cardiac-arrest patients was frequently complicated by adverse effects. The most prominent adverse effects were oxygen desaturation and severe hypotension. The changes had longer duration than what is described in comparable studies on sedated patients. Higher cardiovascular SOFA-score, light sedation and oxygen desaturation prior to suctioning were factors independently associated with increased risk for oxygen desaturation. First ICU day, higher cardiovascular SOFA-score, suction with manual ventilation and combined suction and patient repositioning were identified as risk factors for severe hypotension. Based on the result of this study, oxygen desaturation and hypotension should be anticipated in circulatory compromised patients after cardiac arrest during their first day of ICU care. Furthermore, the results point towards that manual ventilation and combined procedures should be avoided when possible, and that the need for extra sedation with a short-acting hemodynamic stable sedative should be assessed prior to endotracheal suctioning procedures.

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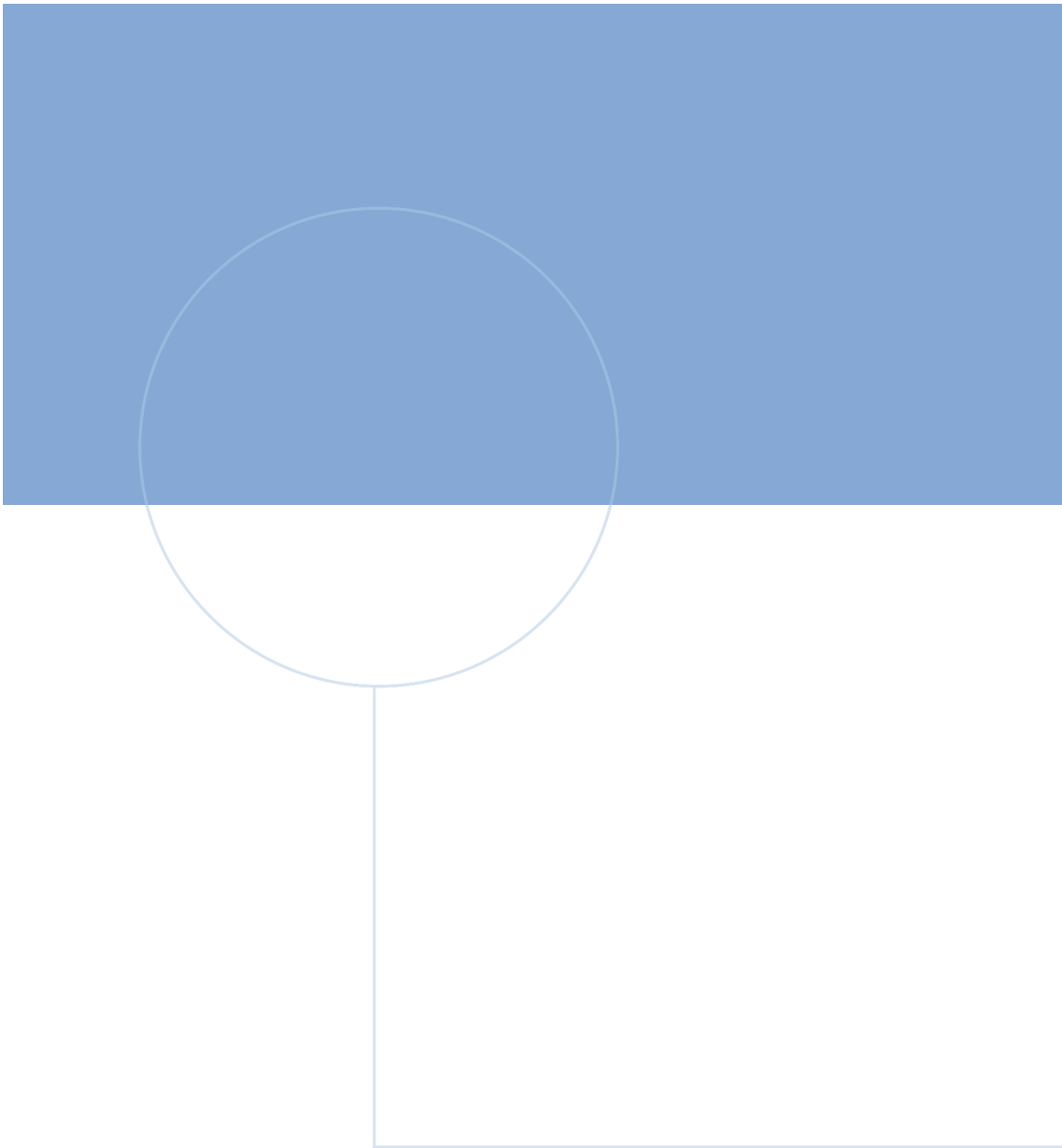

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