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ORIGINAL ARTICLE

Cardiopulmonary resuscitation outcomes of dogs and cats at a veterinary teaching hospital before and after publication of the RECOVER guidelines

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Objectives: To describe and compare cardiopulmonary resuscitation outcomes at a Swiss veterinary teaching hospital before and after publication of the Reassessment Campaign on Veterinary Resuscitation guidelines.

Materials and Methods: Between 2018 and 2020, hospital staff underwent various types of yearly Reassessment Campaign on Veterinary Resuscitation-based cardiopulmonary resuscitation trainings. Canine and feline cardiopulmonary resuscitation events during that period (post-Reassessment Campaign on Veterinary Resuscitation) and between 2010 and 2012 (pre-Reassessment Campaign on Veterinary Resuscitation) were identified and animal, arrest and outcome variables recorded retrospectively. Factors associated with return of spontaneous circulation were determined using multivariable logistic regression, odds ratios (95% confidence interval) generated, and significance set at $P < 0.05$.

Results: Eighty-one animals were included in the pre-Reassessment Campaign on Veterinary Resuscitation group and 190 in the post-Reassessment Campaign on Veterinary Resuscitation group. Twenty-three percent in the pre-Reassessment Campaign on Veterinary Resuscitation group and 28% in the post-Reassessment Campaign on Veterinary Resuscitation group achieved return of spontaneous circulation and 1% and 4% survived to hospital discharge, respectively. Patients undergoing anaesthesia [odds ratio 4.26 (1.76 to 10.27)], elective [odds ratio 5.16 (1.06 to 25.02)] or emergent surgery [odds ratio 3.09 (1.20 to 8.00)], or experiencing cardiopulmonary arrest (CPA) due to arrhythmias [odds ratio 4.31 (1.44 to 12.93)] had higher odds of return of spontaneous circulation, while those with unknown cause of CPA [odds ratio 0.25 (0.08 to 0.78)] had lower odds. Undergoing cardiopulmonary resuscitation in the post-Reassessment Campaign on Veterinary Resuscitation period was not statistically significantly associated with return of spontaneous circulation [odds ratio 1.38 (0.68 to 2.79)].

Clinical Significance: Unchanged odds of return of spontaneous circulation in the post-Reassessment Campaign on Veterinary Resuscitation period could suggest that once-yearly cardiopulmonary resuscitation training is insufficient, effects of animal and tertiary referral hospital variables confounded

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results, guideline benefit is limited, or that compliance during clinical cardiopulmonary resuscitation efforts is too poor for guideline recommendations to have a positive impact. More extensive cardiopulmonary resuscitation training protocols should be established, and the compliance with and outcome benefits of a Reassessment Campaign on Veterinary Resuscitation-based cardiopulmonary resuscitation approach re-evaluated prospectively.

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INTRODUCTION

The prompt initiation of high-quality cardiopulmonary resuscitation (CPR) is the intervention of choice in patients suffering from cardiopulmonary arrest (CPA) and its performance is aimed at establishing return of spontaneous circulation (ROSC) and patient survival to hospital discharge.

In human medicine, the American Heart Association first published evidence-based clinical CPR guidelines in 1992 and updates have been distributed approximately every 5 years thereafter (Adult Advanced Cardiac Life Support 1992a, Guidelines for cardiopulmonary resuscitation and emergency cardiac care. Emergency Cardiac Care Committee and Subcommittees, American Heart Association. Part II. Adult basic life support 1992, Part 3 2000a, Part 6 2000b, Part 4 2005, Hazinski *et al.* 2010; Neumar *et al.* 2015; Kleinman *et al.* 2018; Merchant *et al.* 2020). Before the publication of these guidelines, rates of patient survival to hospital discharge following in-hospital CPA reached less than 25% and had remained unchanged for many years (Blackhall 1987, Taffet *et al.* 1988). In recent decades, ROSC and survival to hospital discharge rates, however, have significantly improved and for in-hospital CPA reach up to 53 and 34%, respectively (Kilgannon *et al.* 2017). Additionally, beneficial effects of CPR guidelines and guideline updates on patient outcomes after CPA have repeatedly been documented (Girotra *et al.* 2012, Salmen *et al.* 2012, McEvoy *et al.* 2014, Anderson *et al.* 2016, Buick *et al.* 2018, Thompson *et al.* 2018, Holmberg *et al.* 2020, Nas *et al.* 2020).

Before 2012, veterinary CPR recommendations were mostly extrapolated from the human literature and a lack of standardisation of veterinary CPR led to widely variable clinical practices (Cole *et al.* 2002, 2003, Plunkett & McMichael 2008, Boller *et al.* 2010, Maton & Smarick 2012). Limited data on veterinary CPR outcomes were available, and early reported ROSC and survival to hospital discharge rates in dogs and cats were comparably low, ranging from 28 to 44% and 3 to 10%, respectively (Kass & Haskins 1992, Wingfield & Van 1992, Hofmeister *et al.* 2009). Higher ROSC rates of up to 58% could be demonstrated in one study adhering to an institutionally standardised CPR algorithm, providing preliminary evidence for the importance of standardised veterinary CPR practices (McIntyre *et al.* 2014).

In 2012, the Reassessment Campaign on Veterinary Resuscitation (RECOVER) initiative published the first evidence-based, clinical consensus guidelines for the practice of small animal CPR (Fletcher *et al.* 2012). Following guideline release, a recent Japanese study demonstrated that implementation of the RECOVER guidelines in clinical practice significantly improves ROSC and survival to hospital discharge rates of dogs undergoing CPR (Kawase *et al.* 2018).

Most studies reporting veterinary CPR outcomes were conducted in the USA, while no data is available on veterinary CPR outcomes in Switzerland (Kass & Haskins 1992, Wingfield & Van 1992, Hofmeister *et al.* 2009, McIntyre *et al.* 2014, Hoehne *et al.* 2019a, 2019b). The aim of this study was to describe and compare CPR outcomes at a Swiss veterinary teaching hospital before and after publication of the RECOVER guidelines and incorporation of their recommendations into institutional CPR training.

MATERIALS AND METHODS

Study design

Outcomes of dogs and cats suffering naturally occurring CPA and undergoing CPR at the Veterinary Teaching Hospital of the University of Bern, Switzerland were retrospectively collected from and compared between two distinct time periods. Dogs and cats that underwent CPR during the years 2010 to 2012 were included in the pre-RECOVER group and those that underwent CPR between 2018 and 2020 in the post-RECOVER group. The three-year pre-RECOVER time period represented CPR patient outcomes before publication of the first evidence-based small animal CPR guidelines in 2012 but for which electronic medical records were available for review (Fletcher *et al.* 2012). Post-RECOVER patient outcomes were studied during the years 2018 to 2020 while conducting regular CPR training and after institutional implementation of prospective, standardised documentation of CPR events in 2018. CPR outcomes between 2013 and 2018 were not analysed in this study due to variability in emergency and intensive care unit (ICU) staffing, hospital staff CPR training, and CPR event recording.

Cardiopulmonary resuscitation (CPR) training and execution

Clinical conduction of CPR and CPR training during the pre-RECOVER period was not standardised and the initiation of intubation, ventilation, chest compressions, patient monitoring, drug administration and defibrillation was at the discretion of the attending clinician.

During the post-RECOVER period, two small animal emergency and critical care specialists (both Diplomates of the American and European Colleges of Veterinary Emergency and Critical Care) including one RECOVER-certified CPR instructor (SNH) were employed at our institution. Mandatory CPR training for incoming emergency and critical care house officers was held once yearly and in 2018 and 2019 consisted of a 1-hour classroom lecture summarising CPR clinical guidelines and a 1.5-hour simulation-based CPR laboratory. Separate lectures and CPR simulations were offered to patient care staff and pre-existing house officers once yearly, but attendance was not mandatory. No CPR refresher training was provided for existing house officers or faculty.

All lecture and simulation teaching sessions were based on RECOVER guideline basic life support (BLS) and advanced life support (ALS) recommendations (Fletcher *et al*. 2012). The CPR simulations used a low-fidelity canine CPR manikin (https://rescuecritters.com/advanced-veterinary-mannikins/advanced-airway-jerry/) that allowed the execution of chest compressions, generation of pulses associated with chest compressions, orotracheal intubation and a chest rise upon administration of positive pressure breaths. An electrocardiogram (ECG) simulator (Phantom 320 simulator, MedTec & Science GmnH, Ottobrunn, Germany) was used to display the commonly encountered cardiac arrest rhythms asystole, pulseless electrical activity, ventricular fibrillation and pulseless ventricular tachycardia. $EtCO_2$ values were provided by the simulation facilitator upon request based on perceived chest compression quality. A debriefing session was held after the conclusion of the simulation scenario, while no feedback on CPR interventions was given to participants during the scenario. While CPR teaching and hands-on training were based on RECOVER guideline recommendations, teaching materials were developed by the senior author (SNH) for internal staff training and attending individuals did not obtain RECOVER rescuer certification.

Due to social distancing requirements in 2020, the yearly CPR lecture was replaced by house officer completion of the RECOVER initiative BLS and ALS online training modules (https://recoverinitiative.org/veterinary-professionals/courses-and-education/cpr-bls-als-cert/). In-person CPR simulation training could not be conducted for any staff members and full RECOVER rescuer certification was not obtained by house officers.

Medical record review and inclusion criteria

In 2018, a German form for standardised reporting of CPR events within our institution was generated. The form was an abbreviated scribe form based on the RECOVER standardised CPR case report form that provided a checklist of important BSL and ALS measures to be implemented and that collected information on length of CPR, observed $EtCO_2$, cardiac arrest rhythms, and types, doses, and frequencies of medical and electrical therapies provided during CPR. After its development, the form was used during simulation-based CPR training to allow rescuer accustomisation and thereafter was available at the two hospital crash stations. For CPR events that occurred between 2018 and 2020, it was requested that CPR reporting forms be prospectively filled out for every CPR event and a copy was provided to investigator SNH for patient inclusion in this study. In addition to prospectively collected CPR event data, the electronical medical record system was searched retrospectively for CPR billing codes during the years of 2018 to 2020. Dogs and cats that underwent CPR during the pre-RECOVER period were solely identified by searching the electronic medical record system for CPR billing codes.

Electronic medical records of identified cases were retrospectively reviewed. For the purpose of this study, CPA was defined as unconsciousness with lack of spontaneous circulation and lack of spontaneous breathing or irregular, gasping breaths only (Boller *et al*. 2016). Animals suffering respiratory arrest only were not included in the study. CPR was defined as an attempt to restore spontaneous circulation by performing chest compressions, and only animals that were administered chest compressions were included in the study (Boller *et al*. 2016). Reported patient outcome variables included no ROSC, any ROSC, and survival to hospital discharge. Any ROSC was defined as clinical signs of spontaneous circulation such as a palpable pulse, systolic blood pressure of more than 60 mmHg, or a marked increase in $EtCO_2$ lasting at least 30 seconds (Boller *et al*. 2016). Causes for no ROSC or non-survival to hospital discharge in patients that achieved ROSC were recorded in accordance with definitions provided by the Utstein-style guidelines on uniform reporting of in-hospital CPR in dogs and cats (Boller *et al*. 2016). Additionally recorded data included animal variables such as species, breed, sex, weight, age and disease category at admission and arrest variables including CPA location, time of day, whether CPA was witnessed, and the suspected cause of CPA as previously defined by the veterinary Utstein-style guidelines (Boller *et al*. 2016).

Statistical analysis

The primary outcome of our study was differences in ROSC rates between the studied time periods and a secondary outcome was differences in rates of survival to hospital discharge. Based on previously published ROSC and survival to hospital discharge rates before and after implementing a RECOVER-based CPR approach, a sample size calculation (ClinCalc online sample size calculator, https://clincalc.com/stats/samplesize.aspx) was conducted to determine the required case numbers for a study with an alpha level of 0.05 with a power of 80% (Kawase *et al*. 2018). A minimum sample size of 48 patients and 152 patients per group was yielded to detect statistically significant differences in pre-RECOVER and post-RECOVER ROSC rates from 17 to 45% and survival to hospital discharge rate from 0 to 5%, respectively (Kawase *et al*. 2018).

Data was collected in a computer spreadsheet programme and information on included cases imported into commercial statistical programmes [Prism 9.0, GraphPad Software; JMP version 16.1.0, SAS Institute Inc.; SPSS Statistics for Windows, version 28.0.1.1.(14)]. Distribution of continuous data was assessed for normality using the Shapiro Wilk test and by examining normal plots. Normally distributed data are presented as mean ± SD and non-normally distributed data are presented as median (range). For categorical data, percentages of group total were calculated. Similar to previously described approaches, univariate analyses were performed to identify independent variables associated with ROSC to be included in multi-variable logistic regression (Hofmeister *et al.* 2009, Hoehne *et al.* 2019a). Univariate binary logistic regression was performed to evaluate the association of CPR time period (pre- *versus* post-RECOVER) and the collected animal and arrest variables with the primary outcome ROSC and variables with a P-value of <0.1 were included in further analysis. A multi-variable binary logistic regression model for the dependent outcome of interest ROSC was subsequently built by first entering the variable “post-RECOVER time period” and in a second step entering all variables identified to be associated with ROSC in univariate analyses in the model in a forward stepwise approach. Model fit was assessed using the Hosmer-Lemeshow goodness of fit test. Odds ratios and 95% confidence interval (CI) were generated and P-values <0.05 considered statistically significant.

Ethical statement

Due to the retrospective nature of the study, need for ethical approval of the study was waived by the institutional review board of the Vetsuisse Faculty at the University of Bern, Switzerland. For CPR event data that was prospectively recorded, recording was part of standard of care record keeping during CPR, and CPR interventions in the post-RECOVER period were conducted according to RECOVER guideline recommendations. Patients during the study period received standard of care interventions that were never altered for the purpose of this study.

RESULTS

Study population included in analyses

A total of 81 case records were identified in the pre-RECOVER period. All cases were included in the study. In the post-RECOVER period, 33 cases that underwent CPR were identified through prospective collection of CPR event data and an additional 170 retrospectively through CPR billing codes. Thirteen cases were excluded from the study because they experienced respiratory arrest only (n=9), CPA was identified but no CPR performed (n=3) and due to lack of documentation of CPR event data in the medical record (n=1), leaving 190 animals in the post-RECOVER group.

Outcome variables

Patient outcomes of the pre-RECOVER and post-RECOVER period are shown in Fig 1. Table 1 summarises animal and arrest variables of patients that did and those that did not achieve ROSC, results of univariate binary logistic regression analyses, and factors statistically significantly associated with ROSC in multi-variable binary logistic regression analysis. When controlling for other animal and arrest variables associated with patient outcome, undergoing CPR in the post-RECOVER period was not statistically significantly associated with increased odds of achieving ROSC [odds ratio 1.38 (95% CI 0.682 to 2.794), P=0.371]. Due to the low number of identified cases that survived to hospital discharge, no statistical comparisons were performed for survival to hospital discharge as the secondary outcome of this study.

In animals that did not achieve ROSC in the pre-RECOVER group, CPR was discontinued due to lack of response to ALS measures in 51 animals (82%), due to owner wishes in nine (15%), and due to poor prognosis perceived by the attending veterinarian in two (3%). Of animals that achieved ROSC but did not survive to hospital discharge, five (28%) were euthanased due to poor prognosis, two (11%) for financial reasons and 11 (61%) suffered another episode of CPA. Repeated CPR in six (55%) remained unsuccessful, in five (45%) animals, it was not attempted.

In the post-RECOVER group, CPR was discontinued due to lack of response in 68 animals (50%), due to owners’ wishes in 50 (36%), and due to veterinarian-perceived poor prognosis in 19 (14%) animals that did not achieve ROSC. Of 46 animals that achieved ROSC but did not survive to hospital discharge, 26 (54%) were euthanased due to poor prognosis, one (2%) due to financial constraints, one (2%) due to a combination thereof and 20 (42%) due to rearrest. Of the 20 animals that suffered repeat CPA, CPR was unsuccessful in 13 (65%) and was not attempted again in seven (35%).

Hospital variables

Records on hospital variables including details on the educational strategy for resuscitation personnel were not available for the pre-RECOVER study period. During the studied time periods, the veterinary teaching hospital at the University of Bern served as a referral-only specialty hospital that provided a 24-hour emergency service and had the capability to provide advanced patient care in an ICU. Crash carts or supplies were available in the emergency and anaesthesia induction room. In the post-RECOVER period, RECOVER CPR algorithms and drug dosing charts were displayed and crash carts fully stocked with a laryngoscope, various size endotracheal tubes, vascular access supplies, ECG, biphasic defibrillator and capnometer. Available drugs included epinephrine, atropine, lidocaine, sodium bicarbonate, naloxone, atipamezole, flumazenil, glucose and calcium gluconate. House officer CPR education in 2018 and 2019 consisted of once yearly RECOVER-based lectures developed by the senior author SNH and simulation training. In 2020, this was replaced by house officer completion of RECOVER initiative BLS and ALS online courses. Veterinary technician and assistant education on small animal CPR consisted of an optional RECOVER-based lecture and simulation training in 2018 and 2019, no training was offered in 2020 and RECOVER rescuer certification was not achieved by attending individuals.

Animal variables

The pre-RECOVER group included 51 (63%) dogs and 30 (37%) cats. Twenty-nine animals (36%) included in this group were male castrated, 17 (21%) were male entire, 23 (28%) female spayed and nine (11%) female entire. The sex or neuter status could not be retrospectively determined in three (4%) animals.

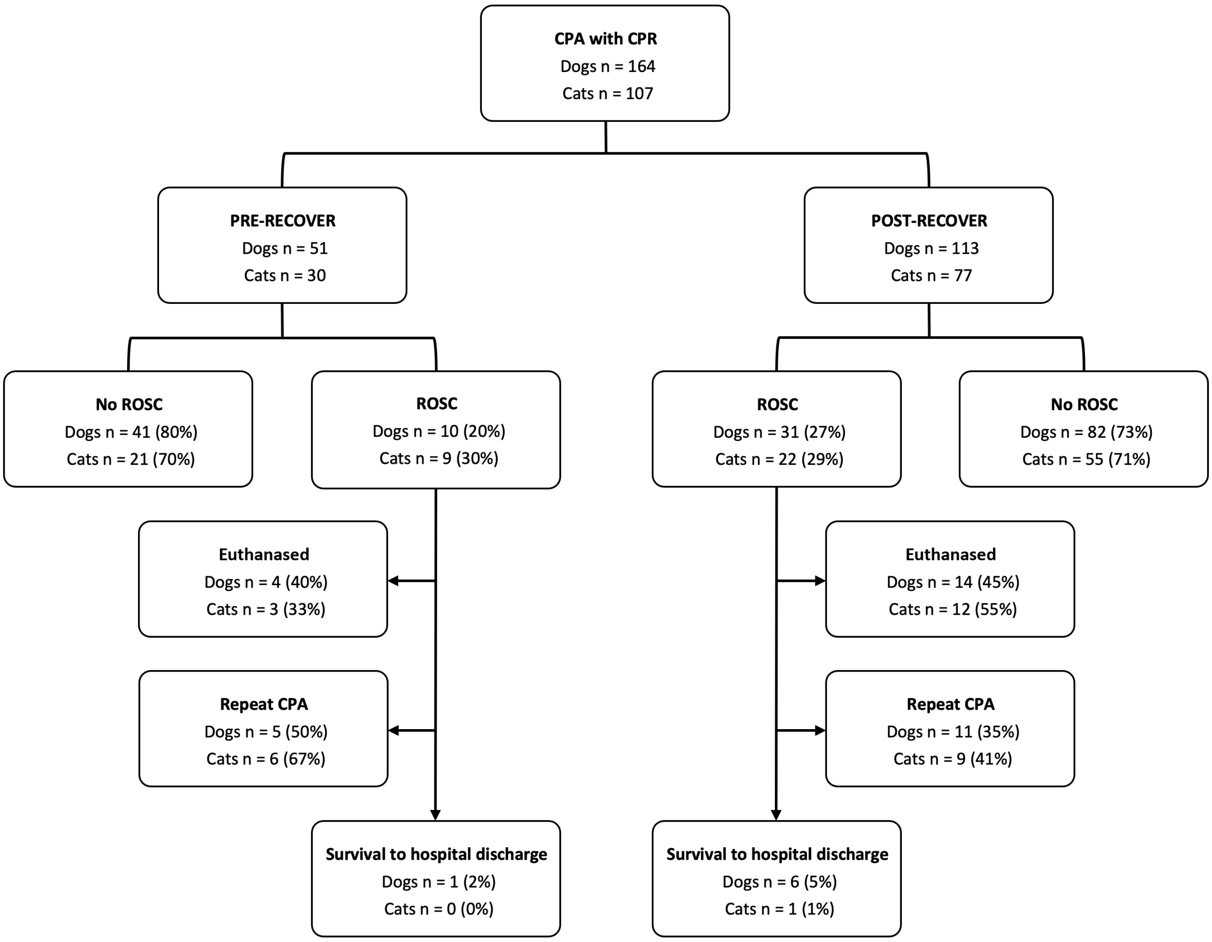

FIG 1. Outcomes of dogs and cats suffering naturally occurring cardiopulmonary arrest and undergoing cardiopulmonary resuscitation at a Swiss veterinary teaching hospital before (pre-RECOVER; 2010 to 2012) and after (post-RECOVER; 2018 to 2020) publication of the 2012 RECOVER veterinary cardiopulmonary resuscitation guidelines. CPA Cardiopulmonary arrest, CPR Cardiopulmonary resuscitation, RECOVER Reassessment Campaign on Veterinary Resuscitation, ROSC Return of spontaneous circulation

A measured or estimated weight could be determined for 64 (79%) of animals and the median (range) was 5.75 (1.2 to 59.6) kg. Median (range) age of 79 (98%) of included animals was 5 years (4 months to 14 years and 4 months). Disease categories at hospital admission can be found in Table 2. At the time of CPA, 10 animals (20%) were under general anaesthesia or sedation.

One-hundred and thirteen (59%) animals included in the post-RECOVER group were dogs and 77 (41%) were cats. Sixty-five animals (34%) included in this group were male castrated, 32 (17%) were male entire, 59 (31%) female spayed and 31 (16%) female entire. The sex could not be retrospectively determined in three (2%) animals. The median weight of 154 (81%) animals in which it could be determined was 5.87 kg, ranging from 1.2 to 77.0 kg. Median (range) age of 185 (97%) included animals was 7 years and 2 months (4 months to 16 years and 10 months). Table 2 summarises disease categories at admission. Nineteen animals (10%) were under general anaesthesia or procedural sedation at the time of CPA.

Arrest variables

Fifty-nine animals (73%) in the pre-RECOVER group suffered CPA during daytime hours of 08.00 to 20.00 hours and 22 (27%) suffered CPA during night-time hours of 20.00 to 08.00 hours during which a smaller veterinary care team is present at our hospital. Cardiopulmonary arrest was witnessed in 73 animals (90%). It occurred in hospital in 72 animals (89%), and out of hospital in nine animals (11%). The exact location of in-hospital CPA could be determined in 69 animals and included the emergency room in 21 animals (30%), ICU in 33 animals (48%), anaesthesia preparation rooms in 10 animals (15%), operating rooms in three animals (4%), and other procedure rooms in two animals (3%). No animals suffered CPA in examination rooms, wards, or the waiting area. Identified suspected causes of CPA are summarised in Table 3. One suspected cause of CPA was identified in 47 (58%) patients, two causes in 14 (17%) patients and three causes in two (3%) patients. In 18 (22%) patients, the cause of CPA remained unknown.

In the post-RECOVER group, 116 animals (61%) suffered CPA during daytime hours between 08.00 and 20.00 hours and 74 (39%) during night-time hours between 20.00 and 08.00 hours. In 161 animals (85%), CPA was witnessed. In-hospital CPA occurred in 165 animals (87%) and out-of-hospital CPA in 25 animals (13%). Of 156 in-hospital CPA for which the exact location could be determined, 52 (33%) occurred in

Table 1. Percentages (95% confidence interval) of animal and arrest variables and results of univariate and multi-variable analyses of factors associated with patient outcome in dogs and cats that did and those that did not achieve return of spontaneous circulation (ROSC) after cardiopulmonary resuscitation (CPR) at a Swiss veterinary teaching hospital during the pre-RECOVER and post-RECOVER time periods

Variable	Outcome, % (95% CI)		Univariate binary logistic regression		Multi-variable binary logistic regression	
	No ROSC	ROSC	OR (95% CI)	P-value	OR (95% CI)	P-value
Study time period						
Pre-RECOVER	77 (66 to 84)	23 (16 to 34)				
Post-RECOVER	72 (65 to 78)	28 (22 to 35)	**1.26 (0.69 to 2.309)**	**0.449**	1.38 (0.682 to 2.794)	0.371
Animal variables						
Species						
Dog	75 (68 to 81)	25 (19 to 32)	0.817 (0.473 to 1.412)	0.47		
Cat	71 (62 to 79)	29 (21 to 38)				
Sex						
Male	71 (63 to 78)	29 (22 to 37)	1.18 (0.684 to 2.036)	0.552		
Female	75 (66 to 81)	25 (19 to 34)				
Neutered	74 (68 to 80)	26 (20 to 32)	0.789 (0.448 to 1.387)	0.41		
Entire	70 (59 to 78)	30 (22 to 41)				
Disease category						
Medical cardiac	68 (47 to 84)	32 (16 to 53)	1.321 (0.516 to 3.384)	0.562		
Medical non-cardiac	78 (70 to 84)	22 (16 to 30)	**0.63 (0.364 to 1.091)**	**0.099**		
Surgical elective	44 (19 to 73)	56 (27 to 81)	**3.638 (0.949 to 13.946)**	**0.06**	**5.16 (1.064 to 25.019)**	**0.042**
Surgical emergent	52 (34 to 69)	48 (31 to 66)	**2.912 (1.296 to 6.544)**	**0.01**	**3.094 (1.196 to 8.003)**	**0.02**
Trauma	71 (57 to 82)	29 (18 to 43)	1.15 (0.566 to 2.338)	0.7		
DOA	86 (71 to 94)	14 (6 to 29)	**0.42 (0.157 to 1.129)**	**0.086**		
Unknown	80 (38 to 96)	20 (4 to 62)	0.687 (0.075 to 6.247)	0.739		
General anaesthesia in place	38 (23 to 56)	62 (44 to 77)	**5.697 (2.537 to 12.791)**	**<0.001**	**4.257 (1.764 to 10.27)**	**0.001**
Arrest variables						
CPR						
Day time	71 (64 to 77)	29 (23 to 36)	1.469 (0.82 to 2.633)	0.196		
Night time	78 (69 to 85)	22 (15 to 31)				
Event witnessed	71 (65 to 77)	29 (23 to 35)	**2.568 (0.96 to 6.87)**	**0.06**		
Out of hospital arrest	85 (70 to 94)	15 (6 to 30)	0.437 (0.163 to 1.178)	0.102		
Location of arrest						
Emergency room	78 (67 to 86)	22 (14 to 33)	0.712 (0.377 to 1.343)	0.294		
Exam room	50 (9 to 91)	50 (9 to 91)	2.789 (0.172 to 45.179)	0.47		
Intensive care unit	75 (67 to 82)	25 (18 to 33)	0.865 (0.501 to 1.492)	0.602		
Wards	0 (n/a)	0 (n/a)				
Anaesthesia	75 (51 to 90)	25 (10 to 49)	0.917 (0.286 to 2.939)	0.884		
Operating room	0 (n/a)	100 (70 to 100)	N/A	0.999		
Procedure room	80 (38 to 96)	20 (4 to 62)	0.687 (0.075 to 6.247)	0.739		
Waiting area	0 (n/a)	0 (n/a)				
Other	56 (27 to 81)	44 (19 to 73)	2.315 (0.604 to 8.879)	0.221		
Suspected cause						
Arrhythmia	38 (18 to 61)	62 (39 to 82)	**5.188 (1.812 to 14.852)**	**0.002**	**4.312 (1.439 to 12.925)**	**0.009**
Respiratory	75 (65 to 83)	25 (17 to 35)	0.867 (0.485 to 1.55)	0.63		
Heart failure	67 (48 to 81)	33 (19 to 52)	1.437 (0.614 to 3.361)	0.404		
Trauma	77 (63 to 87)	23 (13 to 37)	0.783 (0.365 to 1.679)	0.529		
Haemorrhage	58 (36 to 77)	42 (23 to 64)	2.136 (0.823 to 5.545)	0.119		
Hypovolemia	77 (50 to 92)	23 (8 to 50)	0.822 (0.22 to 3.074)	0.771		
CNS disease	80 (55 to 93)	20 (7 to 45)	0.678 (0.186 to 2.473)	0.556		
Sepsis	71 (55 to 84)	29 (16 to 45)	1.123 (0.51 to 2.47)	0.774		
MODS	65 (41 to 83)	35 (17 to 59)	1.554 (0.553 to 4.367)	0.403		
Metabolic	66 (53 to 77)	34 (23 to 47)	1.562 (0.818 to 2.981)	0.176		
Intoxication	52 (34 to 69)	48 (31 to 66)	**2.912 (1.296 to 6.544)**	**0.01**		
Unknown	90 (77 to 96)	10 (4 to 23)	**0.266 (0.091 to 0.777)**	**0.015**	**0.245 (0.078 to 0.777)**	**0.017**
Number of suspected causes			**1.638 (1.093 to 2.456)**	**0.017**		

CI Confidence interval, ROSC Return of spontaneous circulation, OR Odds ratio, RECOVER Reassessment Campaign on Veterinary Resuscitation, DOA Dead on arrival, CNS Central nervous system, MODS Multi-organ dysfunction syndrome

Bolded values in the univariate binary logistic regression column indicate variables statistically significantly associated with achieving ROSC and those inlcuded in the multivariable logistic regression model. Bolded values in the multivariable binary logistic regression columns indicate factors significantly associated with achieving ROSC.

Table 2. Disease category at admission for animals undergoing cardiopulmonary resuscitation at a Swiss veterinary teaching hospital included in the pre-RECOVER and post-RECOVER groups

	Medical, cardiac	Medical, non-cardiac	Surgery, elective	Surgery, emergent	Trauma	DOA	Unknown
Pre-RECOVER, n (%)	5 (6)	33 (41)	3 (4)	15 (19)	14 (17)	9 (11)	2 (2)
Post-RECOVER, n (%)	17 (9)	95 (50)	6 (3)	12 (6)	31 (16)	26 (14)	3 (2)

Results are reported as absolute numbers of animals per group (percentage of group total)
RECOVER Reassessment Campaign on Veterinary Resuscitation, DOA Dead on arrival

Table 3. Identified suspected causes contributing to cardiopulmonary arrest in animals undergoing cardiopulmonary resuscitation at a Swiss veterinary teaching hospital in the pre-RECOVER and post-RECOVER groups

	Arrhythmia	Respiratory insufficiency	Cardiac failure	Trauma	Haemorrhage	Hypovolemia	CNS	Sepsis	MODS	Metabolic	Intoxication	Unknown
Pre-RECOVER, n (%)	2 (2)	23 (23)	4 (4)	13 (13)	5 (5)	2 (2)	1 (1)	6 (6)	4 (4)	10 (10)	11 (11)	18 (18)
Post-RECOVER, n (%)	14 (5)	66 (23)	13 (5)	31 (11)	14 (5)	11 (4)	14 (5)	29 (10)	13 (5)	42 (15)	16 (6)	22 (11)

Results are reported as absolute numbers of animals per groups (percentage of total reported suspected causes). Note that one animal could be assigned more than one suspected cause of arrest
CNS central nervous system disease, MODS multi-organ dysfunction syndrome

the emergency room, two (1%) in an exam room, 87 (56%) in ICU, six (4%) in the anaesthesia preparation room, six (4%) in the operating room and three (2%) in other procedural rooms. No animals suffered CPA in wards or the waiting area. Table 3 summarises all identified suspected causes of CPA in the post-RECOVER group. One suspected cause of CPA was identified in 88 (46%) patients, two causes in 67 (35%) patients, three causes in 11 (6%), and four causes in two (1%) patients. In 22 (12%) patients, the cause of CPA remained unknown.

DISCUSSION

In dogs and cats, undergoing CPR in the post-RECOVER period after publication of RECOVER guidelines and the implementation of their recommendations into once yearly institutionally developed didactic and hands-on CPR training did not significantly increase the odds of achieving ROSC.

In people, adherence to resuscitation guidelines positively impacts CPR patient outcomes, and a recent veterinary study similarly demonstrates improved outcomes of dogs undergoing CPR following the implementation of RECOVER guideline recommendations into clinical practice (Kawase *et al.* 2018, Nas *et al.* 2020). In order to fully assess CPR guideline benefit during two distinctly different time periods, several conditions must likely be met. Firstly, (1) the patient populations studied during the two time periods must be comparable, (2) patient care providers must be aware of guideline existence and recommendations, (3) cognitive skills to implement recommendations must be regularly practiced and (4) acquired knowledge and skills must be applied when performing CPR on clinical patients.

Several hospital, arrest and animal variables are associated with veterinary CPR patient outcomes and include CPA under general anaesthesia or due to drug overdose, witnessed CPA, time of day of CPA, patient bodyweight, number of comorbidities, and nature of suspected cause of CPA (Kass & Haskins 1992, Hofmeister *et al.* 2009, McIntyre *et al.* 2014, Hoehne *et al.* 2019a). In the present study, CPR patients admitted to the hospital for elective or emergent surgical procedures, those under general anaesthesia at the time of CPA, and those with cardiac arrhythmias suspected to be contributing to CPA had higher odds of achieving ROSC, while those with an unknown cause of arrest were 75% less likely to achieve ROSC. Based on our findings and previous veterinary studies, prompt and high-quality CPR interventions therefore seem especially important and rewarding in patients undergoing general anaesthesia (Kass & Haskins 1992; Hofmeister *et al.* 2009; McIntyre *et al.* 2014; Hoehne *et al.* 2019a). Increased odds for ROSC in patients undergoing elective surgery can likely be attributed to similar factors as in patients under general anaesthesia at the time of CPA as most patients scheduled for elective surgery are likely to be systemically healthy or metabolically and cardiovascularly stable. More surprising is the finding that patients admitted to the hospital for emergent surgeries also had increased odds of ROSC as those patients are expected to represent a sicker population. It remains possible that emergent surgical patients included in our study were well stabilised before surgical intervention or that their disease severity was less than expected, however, no measures of disease severity could reliably be determined for all patients undergoing emergency surgery, thus precluding further investigation of this finding. Further, prospective studies should verify this finding while taking objective scores of illness severity into consideration. An association of an initial shockable cardiac arrest rhythm with ROSC rates has previously been documented in dogs (Hoehne *et al.* 2019b). It is likely that patients with arrhythmia as the suspected cause of CPA and those displaying a shockable rhythm as their first cardiac arrest rhythm behave very similarly and it has previously been hypothesised that improved outcomes in this patient population could be due to a specific ALS intervention (*i.e.* electrical defibrillation) being available or that patients with initial shockable cardiac arrest rhythms suffer from less comorbidities that would further negatively impact their outcomes (Hoehne *et al.* 2019b). In contrast to peri-anaesthetic CPA and patients with arrhythmias likely contributing to CPA, patients that suffer CPA due to an unknown inciting cause might represent a patient population with more complex disease and therefore lower odds of ROSC. It is important to acknowledge that our study was carried out at a tertiary referral hospital and animal and arrest variables of the treated patient population are likely very different from patients undergoing CPA at primary or secondary care facilities. This might limit our ability to demonstrate an improvement in CPR outcomes over time. Standardised CPR training and RECOVER guideline compliant CPR conduction could likely achieve a larger impact on patient outcomes in different veterinary care settings tending to more first-opinion cases with lower disease severity (Kawase *et al.* 2018).

A larger proportion of CPR efforts were discontinued due to owner wishes or clinician perceived futility in the post-RECOVER group and in patients that achieved ROSC but did not survive to hospital discharge, a higher proportion of patients were euthanased. Euthanasia represents a confounding factor in all veterinary CPR outcome studies, and it remains possible that more patients in the post-RECOVER group could have achieved ROSC or survived to hospital discharge had CPR efforts been continued or post-cardiac arrest care provided to all.

In people suffering in-hospital CPA, ROSC rates of up to 53%, survival to hospital discharge rates of up to 34%, and an overall trend towards improved patient outcomes and beneficial effects of CPR guideline implementation have been reported (Girotra *et al.* 2012, Salmen *et al.* 2012, McEvoy *et al.* 2014, Anderson *et al.* 2016, Kilgannon *et al.* 2017, Buick *et al.* 2018, Thompson *et al.* 2018, Holmberg *et al.* 2020, Nas *et al.* 2020). Cardiopulmonary resuscitation outcomes of dogs and cats before the publication of the RECOVER guidelines include ROSC rates in dogs of 28 to 60%, in cats of 42 to 57%, and survival to hospital discharge rates in dogs of 3 to 6% and in cats of 2 to 10% (Kass & Haskins 1992, Wingfield & Van 1992, Hofmeister *et al.* 2009, Buckley *et al.* 2011, McIntyre *et al.* 2014). Two studies have re-evaluated CPR patient outcomes since implementation of RECOVER guideline recommendations into clinical practice (Kawase *et al.* 2018, Hoehne *et al.* 2019b). Of those, a Japanese study found a statistically significant increase in canine ROSC rates from 17 to 43% but no significant increase in survival to hospital discharge rates from 0 to 5% after implementing twice yearly RECOVER-based CPR training (Kawase *et al.* 2018). A second, American study reports no significant differences in either ROSC or survival to hospital discharge rates after the implementation of RECOVER guideline recommendations compared to before their publication (McIntyre *et al.* 2014, Hoehne *et al.* 2019b). With 58% of patients achieving ROSC and 5% surviving to hospital discharge, pre-RECOVER patient outcomes reported in the American study were already higher than those reported in Japan, suggesting a benefit of the group's pre-existing standardised approach to CPR (McIntyre *et al.* 2014).

When comparing post-RECOVER ROSC rates at our facility to those previously reported, it appears that a further increase might be achievable. Considering the reported benefits of CPR guideline adherence in people and dogs, differences in animal and arrest variables at a tertiary referral institution and hospital factors more likely explain the lack of statistically significantly improved ROSC rates in the post-RECOVER period than limited guideline benefit. Preparedness factors and hospital factors likely influenced the clinical adherence to RECOVER guideline recommendations. Being prepared to provide high-quality CPR not only requires knowledge of current guideline recommendations, their systematic recall, but also psychomotor skills and an ideal rescuer environment for their correct execution (Boller *et al.* 2012; Boller & Fletcher 2020; McMichael *et al.* 2012).

Post-RECOVER CPR training at our institution either consisted of a lecture on CPR followed by a low-fidelity CPR simulation or the completion of an online CPR training course. Studies examining the impact of manikin fidelity on CPR training yield mixed results. While high-fidelity manikins might improve CPR skill acquisition, they do not conclusively positively influence skill retention or patient outcomes (Cheng *et al.* 2020 p. 6, Cheng *et al.* 2015; Nimbalkar *et al.* 2015; Stellflug & Lowe 2018). Nonetheless, the American Heart Association and RECOVER initiative suggest a potential benefit of and recommend high-fidelity manikins for CPR training (Fletcher *et al.* 2012). High-fidelity simulation benefits mostly lie in the immediate feedback provided to trainees which improves CPR skill acquisition (Lin *et al.* 2018). Therefore, it is possible that house officers at our institution would have benefited more from high-fidelity manikin training or real-time instructor feedback rather than in the form of debriefing.

Due to the COVID-19 pandemic, hands on CPR training of hospital staff was not possible during 1 of the 3 years studied as the post-RECOVER period. While simulation-based CPR training is considered most effective for acquisition of psychomotor skills, there is some evidence that novice rescuers show improved practical CPR skills even after online self-training (Tobase *et al.* 2017, de Sena *et al.* 2019, Cheng *et al.* 2020, Lactona & Suryanto 2021). While this makes it less likely that the transition to online CPR training of incoming house officers was detrimental to the clinical CPR quality provided, it remains possible that better patient outcomes could have been achieved with more consistent RECOVER-based didactic and hands-on training.

In addition to high-quality CPR training, CPR skill retention is influenced by the frequency with which skills are clinically used or reviewed in refresher training sessions. The optimal interval for CPR refresher training in people remains unknown but several studies demonstrate that refresher training sessions up to every 1 to 3 months are associated with improved CPR skills and the American Heart Association Resuscitation Quality Improvement programme suggests quarterly CPR refresher modules and skills checks to maintain BLS and ALS certification (Oermann *et al.* 2011, Sullivan *et al.* 2015, Cheng *et al.* 2018, 2020, Anderson *et al.* 2019, Schmitz *et al.* 2021). Frequent refresher training appears to be most important in novice rescuers, while emergency physicians frequently involved in CPR maintain adequate skills longer (Schmitz *et al.* 2021). Veterinary studies on optimal CPR training intervals to prevent skill decay are lacking but the RECOVER guidelines recommend refresher training be performed at least every 6 months (Fletcher *et al.* 2012). Accordingly, twice yearly training of hospital staff was conducted at the Japanese institution reporting significantly improved ROSC rates in dogs after adopting a RECOVER-based CPR approach (Kawase *et al.* 2018). Intern and resident clinicians frequently represent novice rescuers and as such, it is likely that the once yearly CPR training provided to incoming staff at our institution were insufficient to ensure RECOVER guideline compliant CPR conduction. Similarly, rescuers taking the RECOVER initiative BLS and ALS online training modules would ideally complete a complimentary hands-on CPR training session, as intended by the initiative to achieve full CPR rescuer certification, and at least twice yearly refresher sessions thereafter.

Lastly, a benefit from CPR guideline recommendations can only be expected if the knowledge acquired during CPR training is correctly applied in clinical scenarios. Even though awareness of RECOVER guidelines amongst veterinarians leads to higher rates of self-reported guideline compliant CPR techniques, in contrast to human medicine, such increases in theoretical knowledge have not yet been shown to translate to more guideline compliant CPR execution (Brown *et al.* 2006, Burkhardt *et al.* 2014, Gillespie *et al.* 2019, Lund-Kordahl *et al.* 2019, Kruppert *et al.* 2020). It therefore remains possible that guideline incompliant CPR was delivered at our institution despite RECOVER-based CPR training. Limitations in rescuer environment such as understaffing on shifts outside of regular operational hours could have further contributed to this. Information on RECOVER guideline compliance during CPR conduction could not be determined due to the mostly retrospective nature of this study.

Moving forward, the institutional CPR training strategy should be revised to provide in-depth didactic and hands-on CPR training for all new staff yearly, followed by CPR refresher sessions for all staff every 3 to 6 months. After the implementation of this strategy, RECOVER guideline compliance during CPR efforts and potential benefits on patient outcomes should be prospectively re-evaluated.

Limitations

This study has several limitations. Despite the intended prospective enrolment of post-RECOVER CPR patients, most cases were identified, and information obtained retrospectively. The retrospective study of CPA and CPR events was markedly limited by the information noted in the electronical medical record system as only a minority of retrospectively identified cases had CPR event forms filled out. This precluded comparison of some Utstein-style guideline core variables, such as pre-arrest illness severity, chest conformation, CPR measures in place at the time of CPA, duration of CPR efforts, $EtCO_2$ measurements and ECG diagnoses, and number of rescue drug doses administered during CPR, some of which have previously been shown to be associated with patient outcomes. In addition, information on patient outcomes was limited and a determination if patients achieved sustained ROSC of >20-minute duration could not be made. Since the electronic medical record is typically completed after the conclusion of CPR efforts, it is possible that CPR event data was inaccurate. The prospective collection of all core and supplemental variables as defined by the Utstein-style guidelines in a larger patient population would have allowed for more robust statistical comparisons of patient outcomes.

Finally, the influence of the COVID-19 pandemic on small animal emergency and critical care medicine across the world cannot be ignored. In response to contact precautions, a majority of emergency veterinary hospital reported changes in their operating hours and reduced staff in the face of an increasing case load in 2020 (Wayne & Rozanski 2020a, 2020b). Our institution faced similar challenges, potentially exacerbating impaired adherence to RECOVER guideline recommendations during CPR. It would have been more ideal to assess outcomes of a post-RECOVER patient group without social-distancing mediated changes in CPR teaching strategy, the impact of the pandemic on hospital staffing, and stress levels.

In conclusion, the odds of achieving ROSC were not statistically significantly higher for patients undergoing CPR in the post-RECOVER period after implementing once-yearly RECOVER-based CPR training. In comparison with previous veterinary data, ROSC rates at our facility remained lower in the post-RECOVER period, while the percentage of patients successfully discharged from the hospital were comparable to other institutions. Animal and arrest variables significantly influence CPR patient outcomes and likely differ in patients undergoing CPR at a tertiary referral centre, thus potentially limiting our ability to demonstrate improved ROSC rates in the post-RECOVER period. It is possible that once yearly CPR training is insufficient to allow maximum skill recall and clinical RECOVER guideline adherence and that the frequency of CPR refresher training should be increased but due to the retrospective nature of most of our data collection, we cannot determine the level of guideline compliance. Larger scale, prospective studies of clinical CPR guideline adherence and patient outcomes should then reassess the utility of veterinary CPR guideline recommendations in improving patient outcomes.

Conflict of interest

SNH is a certified RECOVER rescuer and instructor and works as a volunteer for the RECOVER initiative. All service to the RECOVER initiative is provided on a volunteer basis and SNH has no financial conflict of interest. SNH is currently an Associate Editor of the JSAP, but she has not been involved in the peer-review process of this manuscript or any other decisional aspect related to it.

AUTHOR CONTRIBUTIONS

Valentina Dazio: Data curation (lead); formal analysis (supporting); investigation (equal); writing – original draft (equal); writing – review and editing (equal). **John Gay:** Formal analysis (equal); methodology (equal); writing – review and editing (equal). **Sabrina N. Hoehne:** Conceptualization (lead); formal analysis (equal); investigation (equal); methodology (lead); writing – original draft (equal); writing – review and editing (equal).

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