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The effect of a surgical safety checklist on complication rates associated with permanent transvenous pacemaker implantation in dogs☆

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Abstract *Introduction:* To determine whether use of a surgical safety checklist (SSC) would reduce the rate of major complications after permanent transvenous pacemaker implantation in dogs.
Animals: The study included one hundred ninety-nine dogs undergoing pacemaker implantation for bradyarrhythmias at an academic teaching hospital.
Methods: A service-specific SSC was developed and implemented for cardiac catheterization procedures in 2015. Medical records were reviewed to extract relevant clinical and procedural data for cases with (SSC [+]) and without (SSC [−]) a checklist. Owners or referring veterinarians were contacted for outcome and survival data.
Results: Major complications occurred in 25/199 (12.6%) dogs. Incidence of major complications was significantly lower in SSC [+] dogs compared with SSC [−] dogs

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(1/45 procedures vs 24/144 procedures; $p = 0.019$). Dogs with SSCs were more likely to receive antibiotics within 5 min of the first incision ($p = 0.0082$) and to receive antibiotics every 90 min throughout the procedure as prescribed ($p = 0.001$) compared with dogs without SSCs. Incidence of cardiac death was lower in SSC [+] dogs compared with SSC [−] dogs ($p = 0.0012$), but checklist use was not associated with increased survival time (all-cause or cardiac). On average, 91% of checklist components were completed for each SSC; minor changes in record-keeping protocols could increase compliance.

Conclusions: Use of an SSC was associated with a decrease in the major complication rate and an increase in compliance with antibiotic protocols during pacemaker implantation. Results of this study support the use of an SSC in veterinary cardiology procedures.

Abbreviation table

CHF	congestive heart failure
CI	confidence interval
HG-AVB	high-grade atrioventricular block
HR	hazard ratio
NCSU	North Carolina State University
PAP	permanent artificial pacemaker
SSC	surgical safety checklist
SSS	sick sinus syndrome
WHO	World Health Organization

Introduction

Permanent artificial pacemaker (PAP) implantation is the standard of care for treatment of certain bradyarrhythmias in dogs, including high-grade atrioventricular block (HG-AVB) [1], medically refractory sick sinus syndrome (SSS) [2], and persistent atrial standstill [3]. Transvenous pacemaker implantation, performed using a jugular venotomy with the pacing lead placed into the right ventricle under fluoroscopic guidance, is considered the preferred method of pacemaker placement in dogs [4–8].

Although PAP implantation is generally successful and significantly improves survival in dogs with life-threatening bradyarrhythmias [1], this procedure is associated with a relatively high rate of major complications. Published complication rates ranged from 55 to 71% in the 1980s [9,10], decreasing to 13–33% in the 2000s [4–8]. Reports since 2015 suggest major complication rates of approximately 15% for dogs with both HG-AVB [11,12] and SSS [2], while the most recent large-scale multi-institutional retrospective study of 595 dogs with various bradyarrhythmias found a major complication rate of 21.8%.[e] Higher complication rates have been reported in dogs with pre-existing structural heart disease [6], post-operative infections [13], previously used pulse generators [6], inexperienced operators [4], and procedures performed after normal business hours [11]. In comparison, large-scale retrospective studies in humans report major complication rates of 2.3–11.2% [14–17].

A growing body of evidence in human medicine suggests that surgical safety checklists (SSCs) are a useful tool to improve communication among surgical team members and reduce incidence of surgical complications. Based on guidelines published by the World Health Organization (WHO) in 2008, SSCs have been created and implemented in hospitals worldwide [18,19]. Use of SSCs has been associated with significant decreases in rates of death and inpatient complications [20], particularly in developing nations [21]. Clinicians using SSCs overwhelmingly (93.4%) report that they would want SSCs used by the medical team if they were undergoing surgery themselves [22]. However, a large-scale studies across multiple health-care providers found no improvements in mortality or complication rates after implementing an SSC [23], and reviews of the checklist literature have found limited benefits and a risk of bias in studies of SSC efficacy [24]. In summary, SSCs are a promising method of improving health-care outcomes, but positive outcomes are not a given.

Use of SSCs is also an emerging trend in veterinary medicine. Checklists have been used during routine wellness visits to improve completeness of

[e] Whipp C, Stauthammer C, Visser L, Flynn K, Kellihan H, Byun W, Sanders R, Rendahl A. Complications and outcomes of multi-institution transvenous pacemaker implantation. Proceedings of the ACVIM 2018 Forum; 2018 June 14–16; Seattle, WA.

client communication regarding veterinary preventive care [25,26]. Surgical safety checklists in veterinary practice have been mentioned in editorials [27] and letters to the editor [28], and a private referral center in the United Kingdom has described anecdotal positive outcomes with SSC use, including improved teamwork and communication [29]. Recently, a veterinary teaching hospital in Sweden reported that SSCs reduced incidence of complications in small animals undergoing a variety of elective surgeries [30]. In 520 dogs and cats undergoing ovariohysterectomy, mass removal, or orthopedic surgery, use of SSCs led to a reduction in the overall complication rate from 17.3% to 6.8% and particularly decreased incidence of surgical site infections and wound healing complications [30]. These positive outcomes support a role for SSCs in veterinary medicine. To date, no veterinary studies have evaluated the use or efficacy of SSCs in cardiac interventions, particularly in urgent or emergent procedures such as PAP implantation.

The cardiology service at North Carolina State University (NCSU) recently collaborated with a human factors psychologist (ACM) to develop an SSC for use during cardiac catheterization procedures [31]. The purpose of this study was to assess the impact of checklist implementation on complication rates during transvenous PAP implantation. We hypothesized that the rate of major complications would be lower for cases where SSCs were used compared with cases without SSCs.

Animals, materials and methods

Data collection

A retrospective medical record review of all dogs that underwent permanent transvenous pacemaker implantation at the NCSU Veterinary Teaching Hospital between January 1, 2002 and January 1, 2018 was performed. Medical records were reviewed, and the following information was extracted for each patient: signalment; body weight; electrocardiographic diagnosis (HG-AVB, SSS, or persistent atrial standstill); presence of congestive heart failure (CHF) at diagnosis (defined in the following section); the date of pacemaker implantation; starting and ending times of anesthesia and surgery; the expertise level of the primary operator (faculty, first-year resident, second-year resident, or third-year resident); the American Society of Anesthesiologists status; time(s) of antibiotic administration; presence or absence of a cardiology or surgery technician; lead fixation type (passive or active); activation of temporary (transthoracic) pacing during PAP implantation; presence or absence of complications related to PAP placement (defined in the following section), and long-term outcomes and survival (defined in the following section). For cases with PAP implantation after July 2015, the following additional information was collected from the medical record: presence of SSCs in the medical record; the status (checked/unchecked) of each individual checklist item; additional notes written on SSCs; and identity of persons completing (signing) the SSC.

Congestive heart failure was diagnosed presumptively based on a combination of cardiac chamber enlargement on echocardiogram and either radiographic evidence of pulmonary venous distension and pulmonary edema (left-sided CHF), sonographic evidence of cavitary effusion (right-sided CHF), or both (biventricular CHF).

Complications were identified and categorized as major and minor as previously described [4–6,11][e]. Major complications were those considered to be life threatening, capable of causing sudden loss of pacing, or those requiring replacement of the pacemaker system (e.g. lead dislodgment, infection, thrombosis, and right ventricular perforation). Lead thrombosis was diagnosed based on echocardiographic evidence of a newly visualized round or ellipsoid lesion of homogeneous echotexture adhered to the pacing lead, with negative blood cultures and/or the absence of clinical evidence of infection (such as fever, inflammatory leukogram, or systemic clinical signs). Pacing failure was defined as recurrence of bradyarrhythmia due to a lack of PAP capture, with no evidence of lead dislodgment and normal lead impedance measurement.

Minor complications were those considered not life threatening (e.g. wound seromas, minor hemorrhage, minor arrhythmias, and sensing issues). Lead dislodgment was considered a pacemaker complication when it occurred after anesthetic recovery and extubation. A minimum of 6-month follow-up time was required for complications analysis.

Survival was assessed by identifying the date and cause of death, either by medical record review or by contacting owners or referring veterinarians by a phone call or email. The cause of death was categorized as cardiac (including pacemaker related, CHF, or sudden arrhythmic death as assessed by postmortem pacemaker interrogation) or non-cardiac.

Pacemaker implantation

Standardized technique for PAP implantation at NCSU has been previously described [11]. Briefly, dogs were placed under general anesthesia with temporary transthoracic pacing patches affixed to both sides of the hemithorax. Dogs for whom the transthoracic pacing patches were activated received a neuromuscular blockade (atracurium). A right jugular cutdown and venotomy were performed. A bipolar permanent pacing lead was placed in the right ventricular apex under fluoroscopic guidance. Proper lead placement was confirmed by both fluoroscopy and capture threshold testing. A pulse generator was connected to the lead and secured within a muscular pocket in the right dorsolateral neck, and incisions were closed routinely. Leads and generators were obtained through the Companion Animal Pacemaker Registry and Repository (CANPACERS) program. Dogs were hospitalized and monitored for approximately 12—24 h after the procedure before discharge. Antibiotics (cefazolin) were prescribed for intravenous administration perioperatively (at time of the first incision and every 90 min thereafter), and an oral antibiotic (usually cephalexin) was administered orally for 7—10 days after pacemaker implantation, along with a non-steroidal anti-inflammatory medication (usually carprofen).

Surgical safety checklist

A service-specific SSC was developed at NCSU in 2014 in conjunction with the NCSU Department of Psychology's Human Factors and Applied Cognition laboratory. Procedures used to create the SSC and methods of evaluation have been previously described [31]. Briefly, this process involved an initial checklist needs analysis (involving a combination of task analysis and interviews with various team members), identification of goals of the checklist, and assessment of team cultures. In keeping with the WHO principles [19], the checklist was developed as a 'do-verify' list as opposed to a 'to-do' list; in other words, the purpose of the SSC was to make steps in the procedure more explicit and improve communication rather than giving participants a task list to complete. Human factors design principles were followed when creating the final checklist (see Fig. 1), including consideration of the font size, spacing, and visual appeal [31].

The SSC specifies three time points ('time-outs') for checklist use during the procedure: 'just before anesthetic induction'; 'just before incision'; and 'before surgical closure' (see Fig. 1). Roles for specific individuals are clearly defined on the checklist, along with key information to be vocalized. The checklist was fully implemented for all cardiac catheterization procedures at NCSU in July 2015. Following the WHO guidelines for implementation of a checklist, advertising campaign materials were created to create interest and enthusiasm for a 'checklist culture' within the institution [19].

Statistical analysis

Statistical analysis was performed using commercial software.[f] Normality of data was assessed by visual inspection of histograms. Comparisons of variables for PAP procedures with and without SSCs (and with or without a technician present) were performed using Student's *t*-tests for continuous variables and Fisher's exact or Chi-squared analyses for categorical variables. Cox regression analysis was used to assess the relationship between variables and all-cause or cardiac mortality. Dogs that were still alive at the time of writing or were lost to follow-up were included in the survival analysis as censored observations. Significance was set at $p < 0.05$.

Results

Demographic, clinical, and procedural findings

One hundred ninety-nine dogs were included (Table 1). Average age at pacemaker implantation was 10.0 $\pm$ 3.2 years. Commonly represented breeds included Labrador retrievers (n = 22), cocker spaniels (n = 14), beagles (n = 12), miniature schnauzers (n = 12), German shepherd dogs (n = 10), Chow Chows (n = 10), boxers (n = 8), West Highland white terriers (n = 7), and Boston terriers (n = 6). Indications for PAP implantation were HG-AVB (n = 169), SSS (n = 26), and persistent atrial standstill (n = 4). Thirty-three dogs (33/199, 16.6%) had CHF at the time of presentation for pacemaker implantation, distributed as right-sided CHF (n = 17), left-sided CHF (n = 10), or biventricular CHF (n = 6).

One hundred fifty dogs had PAP implanted before SSC implementation in July 2015, while 49

[f] SPSS Statistics, version 24, IBM, Armonk, NY, USA.

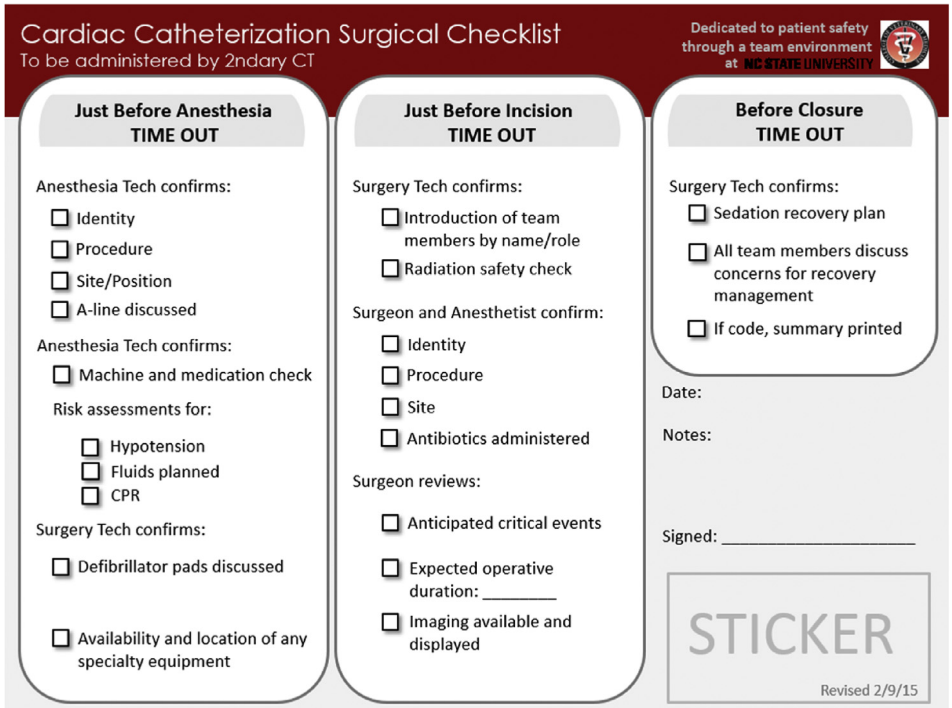

Fig. 1 Service-specific surgical safety checklist developed in conjunction with the NCSU Department of Psychology's Human Factors and Applied Cognition laboratory. CPR, cardiopulmonary resuscitation; NCSU, North Carolina State University.

dogs had PAP implanted after checklist implementation. Checklists were completed for 45/49 (92%) procedures occurring after SSC implementation, resulting in a final population of 45 dogs with SSCs completed (SSC [+]) and 154 dogs without checklists (SSC [−]).

Demographic, clinical, and procedural data for SSC [+] vs SSC [−] dogs are listed in Table 1. Dogs with checklists had lower body weight compared with dogs without checklists ($p = 0.030$). Compared with SSC [−] procedures, SSC [+] procedures were more likely to occur after hours ($p = 0.026$), involve presence of a cardiology or surgery technician ($p < 0.001$), and use active-fixation leads ($p < 0.001$). Dogs with completed SSCs were more likely to receive antibiotics within 5 min of the first incision ($p = 0.0082$), were more likely to continue receiving antibiotics every 90 min throughout the surgery ($p = 0.001$), and received more doses of antibiotics ($p < 0.001$) compared with dogs without SSCs. There were no significant differences between groups for any other clinical or procedural variables analyzed.

Because SSC [+] procedures were more likely to involve presence of an after-hours technician and presence of trained technical staff could affect antibiotic compliance and complication rates independent of the SSC, a subanalysis was performed to investigate the effects of a technician's presence before implementation of SSCs. Of the 150 pre-SSC procedures (before July 2015), technicians were present in 99 cases and absent in 49 cases (data not recorded in two cases). In this subpopulation, presence or absence of a technician did not affect the likelihood of receiving antibiotics within 5 min of the first incision ($p = 1.00$), likelihood of continuing to receive antibiotics every 90 min throughout the surgery ($p = 0.28$), or incidence of major complications ($p = 0.16$).

Complication rates

Major complications occurred in 25/199 (12.6%) dogs (see Table 2). The incidence of major complications was significantly lower in SSC [+] dogs compared with SSC [−] dogs (1/45 procedures vs 24/144 procedures; $p = 0.019$). Median time from pacemaker implantation to major complication was 38 days (range 1–983 days); most major complications (19/25, 76%) occurred within 6 months of PAP implantation. When considering the different specific types of major complications, median time from PAP implantation to

Table 1 Clinical and procedural data for dogs undergoing transvenous permanent artificial pacemaker implantation either with [+] or without [-] a surgical safety checklist (SSC).

Variable	All dogs	SSC [−]	SSC [+]	P value
Number of dogs	199	154	45	–
Age (years)	10.0 ± 3.2	10.0 ± 3.2	9.8 ± 3.1	0.63
Weight (kg)	20.0 ± 11.6	21.0 ± 11.6	16.7 ± 10.9	0.03*
ECG diagnosis	HG-AVB: 169 SSS: 26 PAS: 4	HG-AVB: 131 SSS:19 PAS: 4	HG-AVB: 38 SSS: 7 PAS: 0	0.49
CHF at diagnosis (n, %)	32/199 (16.1)	21/154 (13.6)	11/45 (24)	0.11
After-hour procedures (n, %)	88/196 (44.2)	61/151 (40.4)	27/45 (60)	0.026*
ASA status	3.5 ± 0.7	3.5 ± 0.8	3.5 ± 0.5	0.70
Operator experience (n)	R1: 50 R2: 70 R3: 50 F: 26	R1: 40 R2: 51 R3: 35 F: 25	R1: 10 R2: 19 R3: 15 F: 1	0.052
Presence of cardiology or surgery technician (n, %)	146/196 (74.5)	102/151 (67.5)	44/45 (97)	<0.001*
Temporary pacing activated (n, %)	99/197 (49.7)	71/152 (46.7)	28/45 (62)	0.089
Lead fixation (% active)	25/192 (12.6)	10/147 (6.8)	15/45 (33)	<0.001*
Antibiotics administered within 5 min of incision (n, %)	173/191 (90.6)	128/146 (87.7)	45/45 (100)	0.0082*
Antibiotics administered every 90 min during surgery (n, %)	137/191 (68.8)	96/146 (65.8)	41/45 (91)	0.001*
Total doses of antibiotics administered (n)	1.4 ± 0.6	1.3 ± 0.5	2.0 ± 0.6	0.042*
Surgical duration (min)	91 ± 29	89 ± 28	97 ± 30	0.11
Anesthetic duration (min)	140 ± 50	142 ± 52	134 ± 45	0.18

HG-AVB, high-grade atrioventricular block; SSS, sick sinus syndrome; PAS, persistent atrial standstill; ASA, American Society of Anesthesiologists; R1-3, residents in year 1–3 of American College of Veterinary Internal Medicine-approved cardiology residency training program; F, cardiology faculty; min, minutes.
Continuous data are presented as mean ± standard deviation. The number of dogs with data included is noted for variables with incomplete data sets.
*Indicates statistical significance ($p < 0.05$).

complication was 1 day for lead dislodgment (n = 7), 76 days for lead thrombus (n = 5), 58 days for lead infection (n = 4), 194 days for generator infection (n = 3), 94 days for pacing failure (n = 3), 84 days for lead perforation (n = 2), and 18 days for generator migration (n = 1).

Of major complications noted, 13/25 (52%) eventually resulted in death of the affected dog. Fatal complications were lead or generator infection (n = 4), lead thrombus leading to pulmonary thromboembolism (n = 4) or cranial vena cava syndrome (n = 1), pacing failure (n = 2), Twiddler's syndrome with lead dislodgment (n = 1), and lead perforation of the right ventricle (n = 1). Median time from PAP implantation to diagnosis of a major complication that later proved fatal was

Table 2 Major and minor complication rates in dogs receiving transvenous permanent artificial pacemaker implantation, either with [+] or without [-] completion of a surgical safety checklist (SSC)

Type of complication	All dogs	SSC [−]	SSC [+]	P value
Major complications (n, %)	25/199 (12.6)	24/154 (15.6)	1/45 (2)	0.019[a]
Lead dislodgment	7	7		
Lead infection	4	4		
Lead thrombus	5	5		
Generator infection	3	3		
Generator migration	1	1		
Lead perforation	2	2		
Pacing failure	3	2	1	
Minor complications (n, %)	49/199 (24.6)	37/154 (24.0)	12/45 (26)	0.70
Arrhythmias	31	22	9	
Seroma	10	8	2	
Anesthetic complications	6	5	1	
Muscle twitching	2	2		

[a] Indicates statistical significance ($p < 0.05$).

79 days; median time from PAP implantation to death from a pacemaker complication was 121 days. Incidence of fatal complications was not significantly different for SSC [−] dogs (12/144, 8.3%) vs SSC [+] dogs (1/45, 2%; $p = 0.31$).

Before checklist implementation in July 2015, there had been no significant trends in major complication rate over time at the study institution; the major complication rate did not differ by year in 2001–2014 ($p = 0.85$). The number of procedures per year compared with the number of major complications per year is displayed in Fig. 2.

Minor complications were noted in 49 dogs (see Table 2), all occurring perioperatively or within days of PAP implantation. There was no difference in the minor complication rate between SSC [−] and SSC [+] dogs ($p = 0.70$). Minor complications included ventricular arrhythmias requiring short-term lidocaine treatment (n = 31), seroma formation over pulse generator site (n = 10), muscle twitching (n = 2), and general anesthetic complications such as esophageal stricture, aspiration pneumonia, or acute kidney injury (n = 6). All minor complications resolved with treatment.

Checklist use

Of dogs with PAP procedures after SSC implementation in July 2015, 45/49 (92%) had checklists completed. The four procedures lacking checklists all occurred outside of normal business hours; in two cases, operators forgot to perform the SSC, and in the remaining two cases, clinicians could not locate the SSC paper forms at the time of the procedure. Of the forty-five checklists completed, 41/45 (91%) were properly filed in the patient's medical record and available for review. The overall average completion rate for all components of the SSC (average number of boxes 'checked off') was 91.1%. Individual checklist item completion rates ranged from a high of 40/41 (98%) cases ('Patient Identity,' 'Procedure,' 'Site/Position,' 'A-line discussed,' 'Machine and medication check,' 'Risk assessment for hypotension,' 'Fluids planned,' and 'Defibrillator pads discussed') to a low of 18/41 (43%) cases ('If code, summary printed'). Completion rates for components of the first checklist time-out ('just before anesthesia', mean 97.1%) were higher than those of the second time-out ('just before incision', mean 93.5%; $p < 0.001$), and completion rates for both of these time-outs were higher than that of the third time-out ('before closure', mean 70.7%; $p < 0.002$ and $p = 0.009$, respectively). Average operative duration estimated on SSCs was 87 ± 24 min. Checklists were appropriately dated in 34/41 (83%) cases and properly identified with a patient label in 38/41 (93%) cases. Forms were signed by the individual completing the SSC in32/41 (78%) cases; most commonly, the signing individual was a cardiology or surgery technician (n = 19), although some signatures were illegible (n = 10). The most common additional notes written on checklists referred to cardiopulmonary resuscitation (CPR), either indicating 'no CPR code' occurred (n = 3) or specifying the owner's CPR instructions ('Full CPR', n = 3).

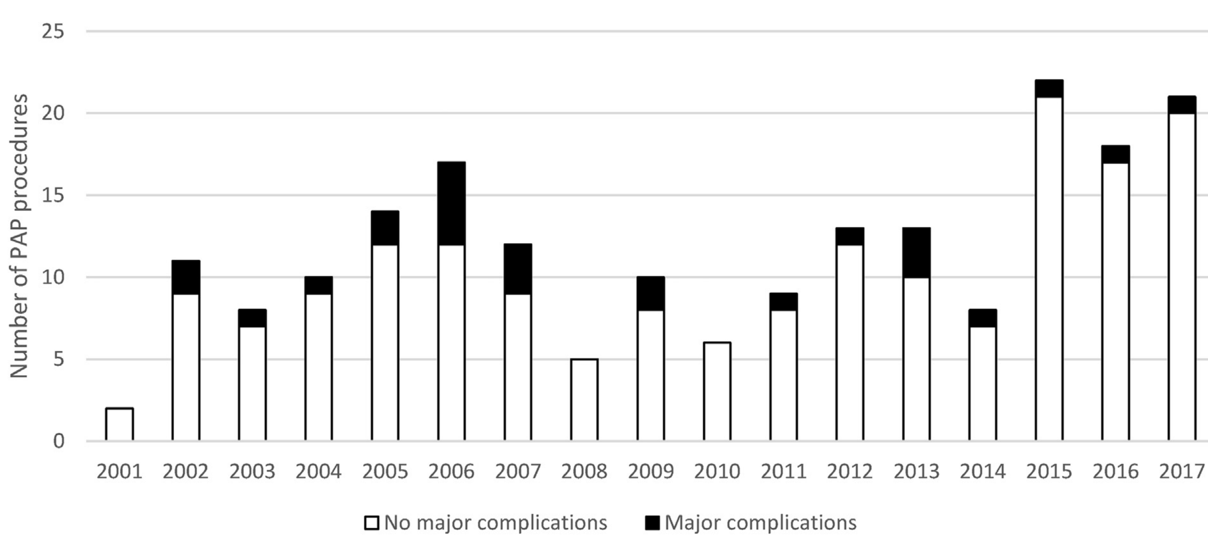

Fig. 2 Total number of transvenous permanent artificial pacemaker procedures performed per year at the study institution, separated as number of procedures with no major complications (white) versus number of procedures resulting in major complications (black). There is no trend in incidence of major complications over time ($p = 0.85$). PAP, permanent artificial pacemaker.

Survival analysis

Long-term follow-up data were available for 176 dogs. Fifty dogs were alive at the time of writing (median follow-up time 553 days), while 126 dogs were no longer alive. Survival to discharge occurred in 174/176 (98.8%) dogs; no perioperative mortality occurred during PAP procedures, but two dogs died in the postoperative period (one dog experienced CHF and neurologic abnormalities after anesthetic recovery, while another developed a hemoabdomen secondary to a ruptured splenic hemangiosarcoma).

Overall median survival time for all dogs was 648 days (range 0—4635 days). Variables associated with shorter survival (all-cause mortality) in multivariate analyses were older age ($p < 0.001$, hazard ratio [HR] 1.301, 95% confidence interval [CI] 1.193—1.419), higher body weight ($p = 0.011$, HR 1.028, 95% CI 1.006—1.050), and use of temporary transthoracic pacing during the procedure ($p = 0.006$, HR 0.530, 95% CI 0.336—0.835).

Of deceased dogs, 90 died or were euthanized for non-cardiac causes, while 36 experienced cardiac death. Of cardiac deaths, 13 dogs died or were euthanized as a direct result of pacemaker complications, 19 dogs died or were euthanized for recurrent CHF, two dogs experienced sudden arrhythmic death (postmortem pacemaker interrogation showed paroxysmal ventricular tachycardia), one dog experienced an aortic thromboembolism, and one dog was euthanized for complications of bacterial endomyocarditis (diagnosed before PAP implantation). Median survival time was shorter for dogs experiencing cardiac death (330 days) compared with non-cardiac death (856 days; $p = 0.0088$). Incidence of cardiac death was lower in SSC [+] dogs (2/45, 4%) compared with SSC [−] dogs (34/131, 26.0%, $p = 0.0012$). Cardiac (versus non-cardiac) death was more common in dogs who had experienced a major PAP complication (14/16, 88%) compared with dogs without major complications (22/90, 24%; $p < 0.001$). When considering cardiac mortality only, presence of a major complication was the only variable associated with shorter survival in multivariate analysis ($p = 0.001$, HR 7.55, 95% CI 2.28—24.96).

Discussion

Results of this study supported our hypothesis that implementation of an SSC for transvenous PAP implantation in dogs was associated with a decrease in the major complication rate (from 15.6% to 2.2%). Furthermore, checklist use was correlated with improved compliance with perioperative antibiotic protocols (administering the first dose of antibiotics within 5 min of incision and repeat dosing of antibiotics every 90 min throughout the procedure). These findings suggest that use of SSCs positively impacted patient care. Given that the most common major complications seen in this study were infection of the PAP system and lead dislodgment, it is plausible that SSCs directly improved surgical outcomes by encouraging proper antibiotic use and improving team communication during PAP implantation.

These results are consistent with human studies that demonstrated similarly significant decreases in surgical complication rates with SSC use. In 2008, as part of its Safe Surgery Saves Lives global initiative, the WHO published and advocated implementation of an SSC adapted from the airline industry [18,19]. The WHO SSC has subsequently been adopted by thousands of hospitals across the globe and is considered part of the routine surgical protocol in many institutions [32]. Numerous studies have shown decreases in surgical complication rates attributed to checklist use (up to 36—66%) [20,33—35], with similar reductions in patient mortality [20,36,37].

Despite the wealth of literature underscoring benefits of SSCs in human hospitals, only one previous study has evaluated the impact of SSCs on complication rates in veterinary surgery [30]. This study involved 520 dogs and cats undergoing a variety of elective surgeries, including fracture repair, subcutaneous mass removal, mastectomy, ovariohysterectomy, and stifle surgery. Similar to the present study, authors used an SSC adapted from the WHO surgical checklist, and cases were temporally separated into 'before and after' checklist procedures. Implementation of SSCs in this setting was associated with a reduction in the overall complication rate from 17.3% to 6.8%. However, a weakness of the previous study was the heterogeneity of the procedure type, which resulted in an unequal distribution of Centers for Disease Control and Prevention surgical classification (clean, clean-contaminated, contaminated, and dirty) between SSC groups. The SSC [−] group included more fracture repairs, mastectomies, and skin lesions, which the authors note may have incurred a higher risk of complications compared with the SSC [+] group independent of checklist completion. In the present study, only a single procedure was investigated (transvenous PAP implantation for bradyarrhythmias), theoretically reducing bias related to morbidity of both procedure and underlying disease.

The historical major complication rate for SSC [−] dogs found in this study (15.6%) is within the range reported in other large-scale retrospective studies of PAP placement in the past 15–20 years (∼15%) [2,4–6,8,11,12]. In contrast, the significantly lower complication rate seen in SSC [+] dogs in this study (2.2%) is within the range reported for PAP implantation in people [14–17]. This suggests that checklist use, when combined with adequate staffing, facilities, and equipment, can allow veterinary cardiologists to achieve similar procedural outcomes to their physician counterparts.

In addition to decreased complication rates, a procedural improvement seen with SSC use in this study was greater adherence to antibiotic protocols. One of the explicit checklist items during the 'just before incision' time-out requires the surgeon and anesthetist to confirm that antibiotics have been administered. It could be argued that the SSC functioned as a 'to-do' check in this context, simply preventing team members from forgetting the vital step of administering antibiotics near the time of the first incision. However, SSC [+] procedures in this study also had greater compliance with repeat administration of antibiotics every 90 min, even though the SSC does not include repeat dosing of antibiotics as a checklist item. It is, therefore, possible that verbalizing the initial dose of antibiotic may have improved individual and team awareness of the overall antibiotic protocol.

While a connection between antibiotic use and infectious PAP complications is relatively logical, it is more difficult to understand how SSC use could directly affect other major complications seen in this study (such as lead dislodgment or lead thrombosis). A similar phenomenon was reported in general veterinary surgery, where the SSC-associated decline in major complications involved not only a reduction in infectious complications but also decreased rates of 'unplanned reoperation' for reasons including refracture or orthopedic implant failure [30]. One explanation is that the decrease in major complication rates may have been statistically driven by declines in infectious complications in both studies. However, it is also possible that SSCs confer intangible, indirect benefits to the health-care team that favorably impact patient safety beyond individual checklist items. One of the major reported benefits of a checklist is to improve communication and create common mental models for team members [31]. By forcing team members to explicitly vocalize their thoughts, they become aware of others' expectations and reminded of their own duties. In this way, the function of checklists extends beyond simply 'prompting' actions or preventing memory lapses. Indeed, in interviews during and after checklist development at NCSU, the most frequently mentioned benefit of the SSC was improved team communication [31].

Although the major complication rate was lower in SSC [+] cases and presence of major complications was a risk factor for cardiac death, there was no association between use of SSCs and survival time (all-cause or cardiac). This differs from results in human medicine, where checklist use was associated not only with lower morbidity but also with lower mortality [20,36,37]. This lack of survival difference based on SSC use may reflect the relatively low incidence of death attributable to pacemaker complications in our canine population (13/126 deaths, 10.3%). Indeed, the only factors found to have an independent association with all-cause mortality in this study were higher patient age, higher body weight, and activation of temporary pacing during the procedure. These findings are in contrast to some previous studies of PAP implantation that found pre-existing heart disease [6] and operator inexperience [4] to be associated with decreased survival. Although older patients may be logically expected to have decreased survival times after PAP, the relationship between body weight and survival seen in the present study is more difficult to explain. Body weight was lower in SSC [+] compared with SSC [−] dogs, which may reflect a temporal shift in clinician preference toward placing transvenous (versus epicardial) pacemakers in smaller dogs. Alternatively, it is possible that weight-based survival trends may be related to changes in average weight of dogs receiving PAP implantation at NCSU over time or that this apparent difference in patient body weight is simply due to chance. The survival impact of temporary pacing is potentially more interesting. At NCSU, temporary transthoracic pacing patches are placed in every patient receiving PAP but are only activated intraoperatively when the heart rate falls critically low before placement of the permanent lead [38]. Activation of temporary pacing can, thus, be considered a surrogate marker for dogs who experience severe bradycardia during PAP implantation. This hemodynamic instability under anesthesia may place such patients at risk for future complications including acute kidney injury, CHF, or myocardial ischemia, and arrhythmias.

Successful implementation of an SSC requires engendering interest and enthusiasm among users to create a 'checklist culture' that encourages checklist use. The cardiology service at NCSU began developing this checklist culture early during the process of service-specific SSC creation, when key individuals participated in one-on-one interviews and group feedback meetings with human factors psychologists. Members of the surgical and anesthesia teams, including technicians, residents, and faculty, were interviewed concerning their roles and information needs during cardiac procedures. By the time of SSC implementation in July 2015, checklist buy-in was already high within the cardiology service and was further augmented by advertising campaign materials throughout the hospital [31].

Data from the present study suggest that the most common barriers to SSC completion were largely logistical and that simple clarifications and changes in record-keeping practices could increase compliance. All four of the cases after July 2015 where SSCs were not completed were emergency procedures that occurred after hours. Stress, fatigue, and personnel limitations likely contributed to operators forgetting to use checklists in two cases; in the other two cases, clinicians simply could not find the SSC paper forms after hours. In four additional cases, SSCs were completed but the paper form was not placed in the medical record for long-term storage. These issues could be solved by designating a standardized location for blank SSC forms within the catheterization laboratory and designating one individual to collect and photocopy or scan completed SSCs the day after each procedure. The authors acknowledge that including the four SSC [−] cases that occurred after July 2015 could introduce bias in the SSC [−] group because the operators were familiar with SSCs during these procedures and may have modified their technical behavior accordingly. However, because this study was testing the effects of actually using a checklist, such cases were still categorized as SSC [−] for purposes of assessing the impact of the intervention.

Overall compliance with SSC completion was high, with an average of 91.1% of items 'checked.' Elements of the first SSC time-out ('just before anesthesia') were nearly always completed; compliance progressively decreased thereafter, with the lowest completion rates recorded for the final time-out ('before closure'). A possible explanation for the declining completion rate of checklist items throughout the procedure comes from aviation research.[g] Termed 'get-home-itis' or 'get-there-itis,' this phenomenon describes a motivational state that can arise as a goal approaches, often resulting in decreased compliance with established procedures and/or increased risk-taking. Two potential interventions may reduce the likelihood of this motivational state altering checklist compliance. First, a 'refresher' training course highlighting the latter half of checklist components may be useful for team members to improve completion of all elements of the SSC. Second, including an explicit direction to 'note importance of completing all checklist items' into the 'before closure' time-out could reorient the team to the importance of completing the checklist.

This study has several limitations related to its retrospective design. The most significant limitation, common to other studies assessing the effects of SSC implementation, is that checklists were introduced on a specific date and used only for procedures after that date. Therefore, the two groups of dogs (SSC [−] and SSC [+]) were not contemporaneous, did not span equal periods of time, and did not contain equal numbers of dogs; rather SSC [−] dogs functioned as a historical control group. Given the fact that no change over time in the major complication rate was noted within the SSC [−] group between 2001 and 2015, the decrease in the complication rate after SSC implementation is unlikely to reflect a more general temporal trend toward improved patient care within the hospital, supporting the conclusion that the SSC positively affected outcomes. Furthermore, preoperative diagnostic testing, surgical technique and equipment, and postoperative management protocols remained consistent throughout the study period. Pacemaker implantation had been performed at this institution for more than 10 years before the beginning of this study period, and the number and training level of personnel available to perform PAP implantation remained relatively constant from year to year (three to four cardiologists and two to three cardiology residents at any given time).

However, certain differences were noted between SSC [+] and SSC [−] groups that reflected the temporal difference in these patient populations and may have affected outcomes. Annual PAP caseload was higher in the years 2015—2017 (coinciding with SSC implementation), which could have improved outcomes by increasing technical skill of operators. Activation of temporary transthoracic pacing was more common in the SSC [+] group, presumably reflecting either trends in clinician preference or chance differences in the patient population. Use of temporary pacing was associated with an

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increased risk of all-cause mortality in this study; therefore, if anything this factor might have biased the SSC [+] group toward a worse outcome, which was not the case. Active-fixation leads were also more common in the SSC [+] group, reflecting changes in the lead type availability through the Companion Animal Pacemaker Registry and Repository program. However, the type of pacing lead was not associated with incidence of complications or mortality in this or previous studies [4,11].

The factors that could plausibly confound the impact of SSCs in this study relate to evolving trends in procedure timing and personnel that occurred at NCSU near the same time as SSC implementation. In 2015, our research group reported an increased incidence of major complications for transvenous PAP procedures performed after hours compared with normal business hours [11]. In response to those findings, personnel policies at NCSU were changed to increase availability of after-hours surgery technicians to assist with emergency PAP implantation. With this increased after-hours technical support, clinicians in turn may have become more comfortable proceeding with PAP implantation after hours. It is reasonable to consider that presence of a trained technician might lead to improved antibiotic compliance and decreased complication rates independent of SSC use. However, subanalysis of PAP implantation procedures before 2015 revealed no difference in antibiotic compliance or major complication rates based on presence or absence of a technician. These findings suggest that SSC use, rather than technician presence, was the most important factor contributing to decreased complication rates in this study. However, given the temporal association between SSC implementation and changes in personnel policies, it is difficult to determine exactly how these variables may have interacted to affect patient outcomes, and it remains possible that the decrease in major complication rate documented in this study may reflect additional variables beyond SSC use alone.

Conclusions

This study found that use of an SSC was associated with decreased major complications and increased compliance with antibiotic protocols during transvenous PAP implantation in a veterinary teaching hospital. Results of this study support the use of an SSC in veterinary cardiology procedures.

Conflict of interest statement

The authors declare no conflicts of interest.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvc.2018.11.001.

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