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Experimental paper

Cardioplegia defibrillation of circulatory and metabolic phase ventricular fibrillation in a swine model☆

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Abstract

Introduction: We previously found potassium cardioplegia followed by rapid calcium reversal (Kplegia) can achieve defibrillation in a swine model of electrical phase of ventricular fibrillation (VF) comparable to standard care.

Hypothesis: Exploring 3 possible potassium dose and timing protocols, we hypothesize Kplegia may benefit resuscitation of longer duration untreated VF.

Methods: Three separate blinded randomized placebo-controlled trials were performed with electrically-induced VF untreated for durations of 6, 9, and 12 min in a swine model. Experimental groups received infusion of 1 or 2 boluses of intravenous (IV) potassium followed by a single calcium reversal bolus. Potassium was replaced by saline in the control groups. Outcomes included: amplitude spectrum area (AMSA) during VF, resulting rhythms, number of defibrillations, return of spontaneous circulation (ROSC), and hemodynamics for 1 h post ROSC. Binomial and interval data outcomes were compared with exact statistics. Serial interval data were assessed with mixed regression models.

Results: Twelve, 12, and 8 animals were included at 6, 9, and 12 min VF durations for a total of 32. ROSC was achieved in: 4/6 Kplegia and 3/6 control animals in the 6 min protocol, ($p = 1.00$), 4/6 Kplegia and 2/6 control animals in the 9 min protocol,($p = 0.57$), and 0/5 Kplegia and 1/3 control animals in the 12 min protocol,($p = 0.38$). Two of 8 Kplegia animals achieved ROSC with chemical defibrillation alone.

Conclusions: The majority of animals achieved ROSC after up to 9 min of untreated VF arrest using K plegia protocols. K plegia requires further optimization for both peripheral IV and intraosseous infusion, and to assess for superiority over standard care.

Institutional Animal Care and Use Committee protocol #15127224.

Keywords: Ventricular fibrillation, Sudden cardiac death, Heart arrest, Potassium, Calcium

Introduction

Ventricular fibrillation (VF) remains an important worldwide cause of sudden cardiac arrest. It has previously been shown that animals can be resuscitated from induced ventricular fibrillation with potassium cardioplegia (Kplegia), with or without calcium reversal.[1–4] Hypothesized benefits include conversion of wasteful VF to asystole with decrease in ventricular myocardial energy usage,[5] and possible spontaneous resumption of sinus rhythm after reversal of the hyperkalemic state obviating the need for electrical defibrillation and possible associated myocardial

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stunning.[2,4] Our previous observations of termination of electrical phase VF with Kplegia in a swine model suggest further exploration of this novel therapy for more prolonged VF is warranted.[4]

Human studies suggest patients may benefit from a period of chest compressions prior to defibrillation for VF arrest greater than 5 min duration.[6,7] Chest compressions may serve to resupply vital nutrients such as oxygen prior to defibrillation and return of spontaneous circulation (ROSC). It is possible such patients could also benefit from transient Kplegia to decrease myocardial nutrient demand during this critical resuscitation period.

The optimal dosing and timing of potassium and calcium intravenous (IV) infusions for Kplegia-assisted resuscitation of VF is unknown. The purpose of this series of three randomized blinded placebo controlled experiments was to explore three increasing potassium dosing and timing protocols to treat three increasing durations of prolonged VF to assess for the greatest benefit, if any, in comparison to a standard resuscitation approach based on a variety of outcome measures.

Methods

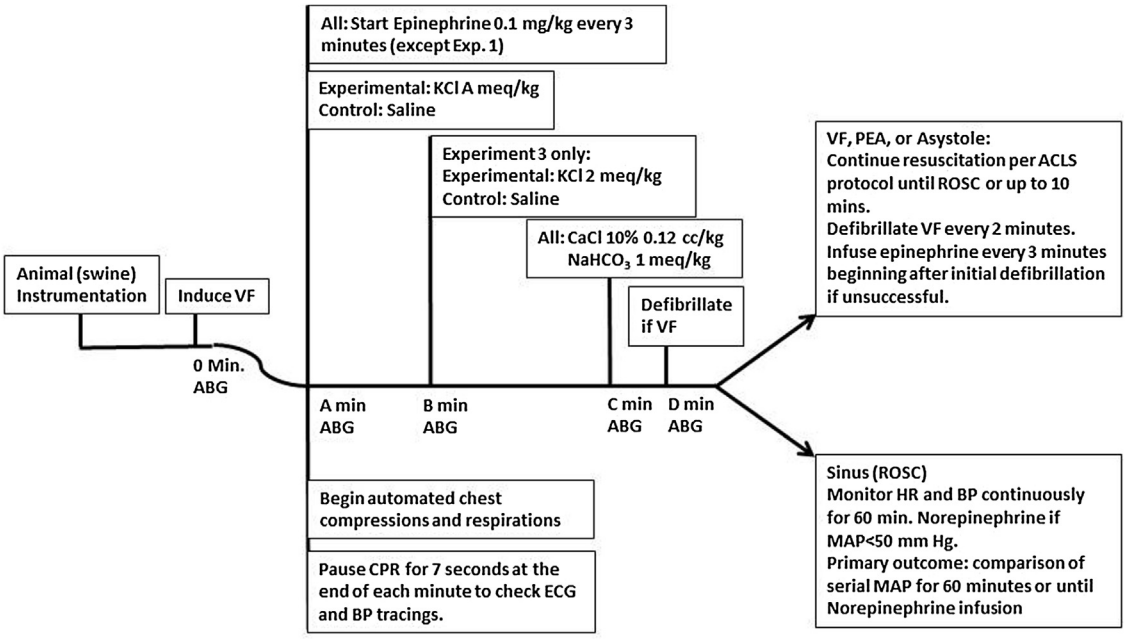
We conducted a series of three randomized, blinded, placebo controlled trials of potassium followed by calcium infusion in a swine VF arrest model. The Institutional Animal Care and Use Committee (protocol 15127224) approved the study, and it was performed in compliance with the Guide for the Care and Use of Laboratory Animals.[8] Thirty two mixed-breed domestic swine (*Sus scrofa*) with mean mass 26.0 kg were used. The swine included males and females in a 1:1 ratio in each experiment. Three experiments were performed with untreated times of 6, 9, and 12 min after electrical induction of VF, and including 12, 12, and 8 animals, respectively. Twelve animals were originally planned for each experiment, but the third experiment was stopped early for futility.

Study protocol

We sedated the animals with intramuscular ketamine (10 mg/kg) and xylazine (4 mg/kg). We then established IV access via a peripheral ear vein using a 20 g catheter. We established a surgical plane of anesthesia using a rapid IV infusion of fentanyl (0.05 mg/kg), maintaining this with a continuous titrated infusion of the same (0.03–0.100 mg/kg/hr), and we paralyzed the animals with vecuronium (4 mg initial bolus IV with additional 2 mg boluses as needed).

We intubated the animals by direct laryngoscopy with a 5–0 cuffed endotracheal tube, ventilated with FiO2 21% at 12–16 breaths per minute using an Ohmeda 7000 ventilator (BOC Health Care, Madison, WI), and titrated ventilation to maintain eucapnia as measured with a mainstream capnometer (Capnostat, Respironics, Wallingford, CT). We used an esophageal temperature probe and digital thermometer unit (T-Pod, ADInstruments, Dunedin, New Zealand) to monitor core body temperature. After shaving the animals' forelimbs, we placed three surface electrodes configured to correspond to a standard Lead II ECG. The ECG signal was passed through a 50 Hz lowpass preamplifier and digitized at 1000 samples/second (Powerlab 16/30 Model ML880, ADInstruments, Dunedin, New Zealand).

We inserted micromanometer-tipped catheters (Millar, Houston, TX) into the descending aorta and right atria via 9Fr. introducers placed in the



Exp.	A min	A KCl dose	B min	B KCl dose	C min	D min
1	6	1.5	None	None	8	10
2	9	2.2	None	None	12	13
3	12	2	14	2	17	18

Fig. 1 – Potassium cardioplegia with calcium reversal for prolonged duration ventricular fibrillation arrest experimental schematic.

right femoral artery and vein, respectively. We achieved access using a cut-down technique for the 6 and 12 min downtime experiments, and using the Seldinger technique for the 9 min experiment. The Seldinger technique was used when the introducer kit and bedside ultrasound were available. We monitored arterial and venous pressures continuously with the same data acquisition system used to record the ECG. For each animal, we sampled blood from the femoral artery introducer access port for blood gas and electrolyte measurements per protocol (Portable Clinical Analyzer, I-Stat, Heska Corp. Wakesha, WA).

One investigator (ACK) prepared the experimental potassium chloride cardioplegic or normal saline (NS) control weight-based infusion agent using a computer randomization scheme with stratification on animal sex. She assisted data collection but made no resuscitation decisions or actions. All other investigators were blinded to the identity of the infusion agent throughout the experiment. The investigator directing the resuscitation (KAM) was also blinded to the telemetry and pressure monitor tracings from study medicine infusion to the initiation of electrical defibrillations, as indicated.

Schematics of the three experimental protocols are shown in Fig. 1. We induced VF transthoracically by delivering a three second, 60 Hz, 100 mA alternating current, and confirmed persistent VF by examination of the ECG and arterial waveform tracings. After 6, 9, or 12 min of untreated VF arrest, we infused potassium chloride in a volume of 20 ml or identical appearing normal saline (NS) placebo in a peripheral ear IV. In the first two experiments, we infused Potassium chloride as a single dose of 1.5 or 2.2. In the third experiment, we infused an initial 2.0 meq/kg dose of potassium chloride, and then a second 2.0 meq/kg dose 2 min later. Our reasoning was to infuse progressively larger doses of potassium to maintain asystole and rest the myocardium for progressively longer durations prior to calcium reversal. Simultaneously with the initial infusion of potassium chloride, we began closed-chest CPR using mechanical compressions with a LUCAS device (Jolife AB / Physio-Control, Lund, Sweden) at a rate of 100 compressions/minute and resumed asynchronous mechanical ventilation with 100% FiO2 at a rate of 12−16 breathes per minute with adjustment to maintain eucapnia as before. We halted chest compressions for 7 s at the end of each minute beginning after infusion of the experimental agent to allow rhythm observation and ECG recording without interference.

We delivered a single dose of calcium chloride, 10% solution 0.12 cc/kg with total volume approximately 3 mL into a peripheral vein and sodium bicarbonate 1 meq/kg with total volume approximately 26 ml into the right atrial catheter 2, 3, and 5 min after the initial KCl dose in each of the three experiments, respectively. In the first experiment, immediately after the first defibrillation, we initiated administration of adrenaline (epinephrine) 0.1 mg/kg every 3 min if the animal did not achieve return of spontaneous circulation (ROSC). In the second and third experiments, we administered epinephrine 0.1 mg/kg every 3 min along with the initial KCl dose at the start of chest compressions. Given the longer durations of untreated VF in the second and third experiments, we administered epinephrine with initiation of chest compressions to improve survival. We used high dose epinephrine due to the high proportion of ROSC and survival previously achieved with this dosing in our laboratory.[9] We defined ROSC as a persistent perfusing rhythm with systolic aortic blood pressure of at least 60 mm Hg for at least 10 consecutive minutes.

Beginning with the initial KCl infusion, we provided chest compressions and ventilations for 4 min in the first two experiments, and for 6 min in the third experiment, followed by assessment for a shockable rhythm. We attempted biphasic defibrillation with 150 J as appropriate via bilateral chest paddles. If the animal demonstrated a nonperfusing rhythm based on arterial waveform, we provided standard advanced cardiac life support (ACLS) measures including: continued mechanical chest compressions and ventilations, 0.1 mg/kg epinephrine infusion every 3 min, and rhythm check for possible defibrillation every 2 min. We continued this protocol until the animal achieved ROSC. If ROSC was not achieved after 10 min of ACLS, resuscitation efforts were ceased.

If the animal achieved ROSC, then we observed it for 60 min post-ROSC, including monitoring of heart rate, arterial and venous blood pressure (BP), and electrocardiographic tracing. If the animal developed a mean arterial pressure (MAP) less than 50 mm Hg, then we initiated norepinephrine pressor infusion with titrated dosing to maintain blood pressure above MAP 50 mm Hg. We chose a low BP treatment threshold to allow maximal observation and comparison prior to intervention. We euthanized surviving animals after the observation period with a rapid IV infusion of 40 mEq KCl.

Measurements

The amplitude-spectral area (AMSA) is a quantitative waveform measurement associated with successful defibrillation, ROSC, and survival.[10,11] KPlegia is expected to decrease AMSA in association with temporary asystole induction, but AMSA could subsequently improve in association with any beneficial energy dynamics. We calculated AMSA for animals in VF using a 3 s ECG epoch obtained 20 s after VF induction and then during the 7 s cessation of chest compressions each minute beginning just before the first experimental infusion. AMSA was computed as described by Povoas and Bisera.[12]

We recorded the proportion of animals achieving ROSC, whether it was achieved via chemical or electrical defibrillation, the number of shocks required, if any, and the time until ROSC after initiating resuscitation. We also recorded the number of animals requiring norepinephrine infusion and the time from ROSC to initiation of norepinephrine infusion, and the number of animals with recurrent cardiac arrest and the proportion of animals surviving to one hour post ROSC.

We calculated CPP as the average difference between the aortic and central venous pressure over 200 ms just before the onset of chest compressions and then after the final compression at the start of each 7 s pause or during diastole for those animals that achieved ROSC. We measured ABG and electrolytes before VF induction and as marked in the schematic for each experiment. We classified ABG potassium values greater than 9.0 mmol/L (upper bound of clinical analyzer K + reporting range) with a value of 10.0 for subsequent calculations. We measured electrocardiographic QRS interval in all animals with an organized rhythm.

We measured the hemodynamics of resuscitated animals including the MAP and mean heart rate over 5 s every minute for 60 min after ROSC or until initiation of norepinephrine. We used the cyclic measurement feature of Labchart (Version 8, ADInstruments, Sydney, Australia) to determine average MAP over 5 s epochs. MAP serves as a surrogate marker of LV function in this experiment, though it may be confounded by a host of factors such as vascular tone, adrenergic treatment, and heart rate.

Table 1 – Primary resuscitation results.

Experiment	Treatment	Animals	Chemical defib	Electrical defib (Ave. # shocks req)	ROSC	Recurrent arrest	Norepi	Norepi mean post-ROSC start time (min)	Survival to protocol completion
1	Saline	6	0	3 (2)	3	1	2	8	3
	Potassium	6	1	3 (2)	4	0	3	22	4
2	Saline	6	0	2 (1)	2	1	1	17	2
	Potassium	6	1	3 (3.3)	4	0	3	16	4
3	Saline	3	0	1 (2)	1	0	0	–	1
	Potassium	5	0	0	0	0	0	–	0

Defib = Defibrillation, Norepi = Norepinephrine infusion, ROSC = return of spontaneous circulation.

Table 2 – Selected arterial blood gas results.

Experiment 1		Summary data: (6 control, 6 experimental)							
		Treatment	0	6	8	10	5 p ROSC	10 p ROSC	15 p ROSC
	Ave pH	Experimental	7.53	7.42	7.21	7.30	7.21 (4)	7.28 (3)	7.14 (1)
		Control	7.49	7.42	7.23	7.40	7.22 (3)	7.28 (3)	
	Ave pCO2	Experimental	33.4	43.6	64.1	66.5	61.9 (4)	53.1 (3)	58.0 (1)
		Control	36.1	40.6	52.5	50.6	51.4 (3)	45.2 (3)	
	Ave HCO3	Experimental	27.2	27.6	25.1	31.7	24.6 (4)	24.8 (3)	19.9 (1)
		Control	27.1	26.4	21.9	31.9	20.8 (3)	20.9 (3)	
	Ave K	Experimental	3.6	4.5	10.0	10.0	6.8 (4)	5.0 (3)	4.7 (1)
		Control	3.6	3.9	7.5	6.6	3.8 (3)	3.5 (3)	
	Ave Ca	Experimental	1.25	1.25	1.23	1.66	1.30 (4)	1.17 (3)	1.48 (1)
		Control	1.33	1.30	1.33	1.14	1.19 (3)	1.14 (3)	

Experiment 2		Summary data: (6 control, 6 experimental)						
		Treatment	0	9	12	13	5 p ROSC	10 p ROSC
	Ave pH	Experimental	7.50	7.39	7.11	7.25	7.10 (4)	7.08 (4)
		Control	7.49	7.36	7.26	7.31 (5)	7.22 (2)	7.07 (1)
	Ave pCO2	Experimental	36.0	50.5	86.4	115.7	62.5 (4)	63.1 (4)
		Control	39.5	49.7	55.0	89.5 (5)	67.2 (2)	72.5 (1)
	Ave HCO3	Experimental	28.0	30.5	27.2	51.6 (5)	19.3 (4)	18.9 (4)
		Control	28.3	27.4	23.9	43.8 (4)	27.7 (2)	21.1 (1)
	Ave K	Experimental	3.4	3.8	10.0	10.0	8.2 (4)	7.5 (4)
		Control	3.7	4.3	7.0	7.5 (5)	8.7 (2)	6.3 (1)
	Ave Ca	Experimental	1.17	1.23	1.22	2.42	1.23 (4)	1.17 (4)
		Control	1.26	1.22	1.26	2.07 (5)	1.49 (2)	1.33 (1)

Experiment 3		Summary data: (3 control, 5 experimental)						
		Treatment	0	12	14	17	18	20 p ROSC
	Ave pH	Experimental	7.47	7.35	7.2	7.04	7.11	
		Control	7.49	7.38	7.25	7.16	7.29	7.15 (1)
	Ave pCO2	Experimental	37.6	51.2	58.0	91.5	100.7	
		Control	26.0	48.0	47.7	49.7	74.2	53.0 (1)
	Ave HCO3	Experimental	27.6	28.4	21.8	22.1 (4)	32.5	
		Control	29.5	27.9	19.8	17.3	35.3	18.5 (1)
	Ave K	Experimental	3.5	4.9	10.0	10.0	10.0	
		Control	3.7	3.7	5.7	5.2	4.7	3.1 (1)
	Ave Ca	Experimental	1.30	1.27	1.10	1.19	1.90	
		Control	1.30	1.14	1.16	1.02	1.31	1.15 (1)

Average values for each experiment, treatment group, and time (minutes) from VF induction. If there were less than the original number of animals, then the number is provided in parenthesis.
Units of measure were: pCO2 mm Hg, HCO3 mmol/L, K mmol/L, Ca mg/dl.

Analysis

We performed univariate comparisons of interval data between the Kplegia and placebo groups using the nonparametric Hodges –Lehmann confidence interval for median shift. If exact confidence interval statistics could not be computed, then we used asymptotic estimates and checked with bootstrapped estimates. We compared binomial data such as the number of animals achieving ROSC using Fisher's exact test.

We constructed random-effects mixed linear regression models to assess CPP from just before the start of resuscitation to ROSC or first defibrillation attempt, and to model MAP from ROSC to initiation of norepinephrine infusion or completion of the experiment one hour post ROSC. We used such models to maximize statistical power obtained from repeated measures on each animal, but limiting the total number of animals used. In the first model, the dependent variable was CPP. Treatment group and time, shifted to center time = 0 half way between the onset of chest compressions and planned first defibrillation, and their interaction, were represented by three fixed variables. Multiple serial measurements were clustered for each animal, and the individual animal intercepts at time = 0 were also represented by one random variable. In order to insure a parsimonious model that converged, time was not represented as a random variable too, and no residual covariance was assumed.

For the second model, the dependent variable was MAP post ROSC. Fixed variables included: time post ROSC, treatment group, and its interaction with time. A quadratic term, time squared, was also added if it improved fit based on variable significance, AIC, and the likelihood ratio test. Random variables included the intercept and time post ROSC (slope) grouped by animal, as above. The random variable variance-covariance matrix was unstructured and residual covariance was assumed to be zero. Sample size was approximated to allow sufficient power for comparisons of repeated measures with uncertain variance. We computed statistics using R 3.4.1 (R Foundation for Statistical Computing, Vienna, Austria) and the DescTools, Boot, and nlme packages, and we also computed mixed linear regression with SAS 9.4 (SAS Institute, Cary, North Carolina).

Results

Major results are listed in Table 1 including: the number of animals that achieved chemical or electrical defibrillation, the average number of shocks required if the later, the total number of animals achieving ROSC, and the number with recurrent cardiac arrest. Table 1 also lists: the number of animals requiring norepinephrine infusion, the time to norepinephrine initiation post ROSC, and the number of animals surviving to protocol completion one hour post ROSC. None of these results were statistically significantly different between control and treatment groups in each experiment. Summary ABG data are provided in Table 2.

The median shift between control and experimental groups of the difference in AMSA from just before initiation of chest compressions to before the first electrical defibrillation was −0.41 (95% CI −0.95 to 0.20) and −0.76 (95% CI −1.29 to 0.22) in experiments one and two, respectively. AMSA increased more, though not significantly, with resuscitation in the control groups (Fig. 2). This difference was not computed for experiment three as all but one animal in each group was in asystole or PEA.

Regarding time durations, the median shift between control and experimental groups of the time from initiation of resuscitation to ROSC for those animals achieving ROSC was 0 (95% CI −4.0 to 8.0) and 6.5 (95% CI 4.0 to 24.0) in experiments one and two, respectively. Time to ROSC was longer in the experimental group in experiment two. Only one animal achieved ROSC in experiment three. The median shift between control and experimental groups in the time from ROSC to initiation of norepinephrine infusion was 11.0 (95% CI 1.0 to 33.0) and −4.0 (95% CI −4.0 to 28.0) in experiments one and two, respectively. Two of three experimental group animals in experiment two had a time of zero because norepinephrine was initiated for pseudo-PEA prior to ROSC. All shift confidence intervals were also computed using a bootstrapping approach with similar results.

CPP for each experiment is graphed in Fig. 3. The time*treatment group interaction slopes for experiments one through three, respectively, were: −2.3 (95% CI −5.4 to 0.8), −2.5 (95% CI −8.6 to 3.5), and 2.6 (95% CI −1.5 to 6.7). A negative point estimate suggests a smaller slope and increase in CPP in the treatment group.

MAP post ROSC for the surviving animals in experiments one and two are plotted in Fig. 4. The experiment one model, but not experiment two, benefited from inclusion of a fixed quadratic term in time, time^2. The time*treatment group interaction slopes for experiments one and two, respectively, were: 1.7 (95% CI −0.9 to 4.3) and 10.8 (95% CI −12.0 to 33.5). A positive point estimate suggests a larger slope and slower decrease in MAP in the treatment group.

Discussion

We previously demonstrated that potassium plegia with calcium reversal, "Kplegia," can terminate electrical phase VF chemically in an electrically induced VF porcine model.[4] The purpose of this series of experiments was to explore higher potassium doses and durations of Kplegia for termination of longer duration VF.

We progressively increased the duration of untreated VF from 6 to 12 min in 3 experiments, and simultaneously increased the potassium dose and duration of Kplegia. Our goals were to determine if Kplegia can successfully terminate circulatory or metabolic phase VF as compared to a control regimen, and to explore the optimal Kplegia regimen. The ideal potassium dose, number of doses, and duration of plegia are unknown.

Kplegia performed comparably to control therapy in experiments one and two by most measures. Point estimates for ROSC and survival were better for Kplegia, but these were not statistically significant. Two of eight treatment group animals that had ROSC in experiments one and two were chemically defibrillated without the need for electrical shock. Recurrent arrest was only observed in control animals. In experiment three we used two higher doses of potassium to provide prolonged five minute plegia until calcium reversal for the resuscitation of 12 min untreated VF. This protocol failed with no treatment group animals successfully resuscitated. Serum potassium remained ≥10 meq/L throughout the resuscitation in the five treatment group animals. This could have been the cause of failure, or perhaps prolonged plegia and asystole were detrimental for other unknown reasons. For example, it is conceivable that *less* potassium is required to induce and sustain asystole after more prolonged VF arrest with more depleted myocardial substrate reserves.

We hypothesized Kplegia may ultimately benefit AMSA after the return of VF from asystole by preserving myocardial energy

expenditure. The point estimates were for a detrimental effect of Kplegia on AMSA, and this may have been due to incomplete recovery from plegic asystole or hyperkalemia. Asystole resulting from Kplegia could be beneficial or detrimental to CPP during resuscitation. We

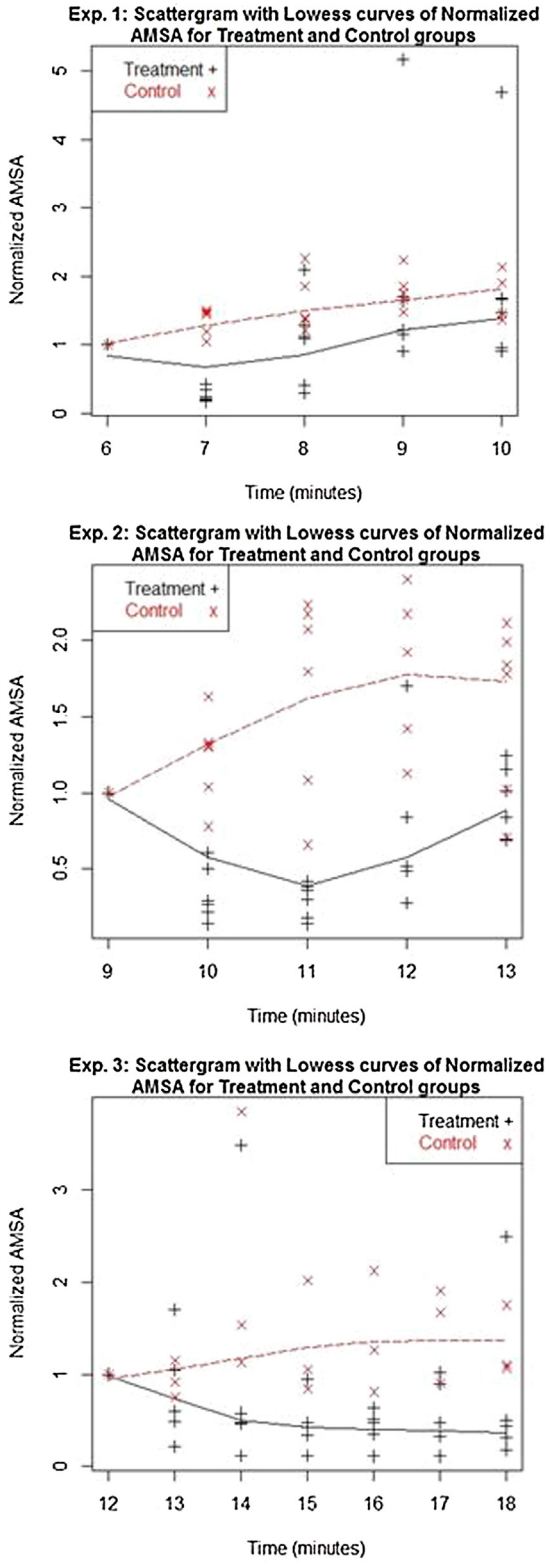


Fig. 2 – Scattergrams with Lowess curves of Normalized AMSA for Treatment and Control Groups in Experiments.1–3.

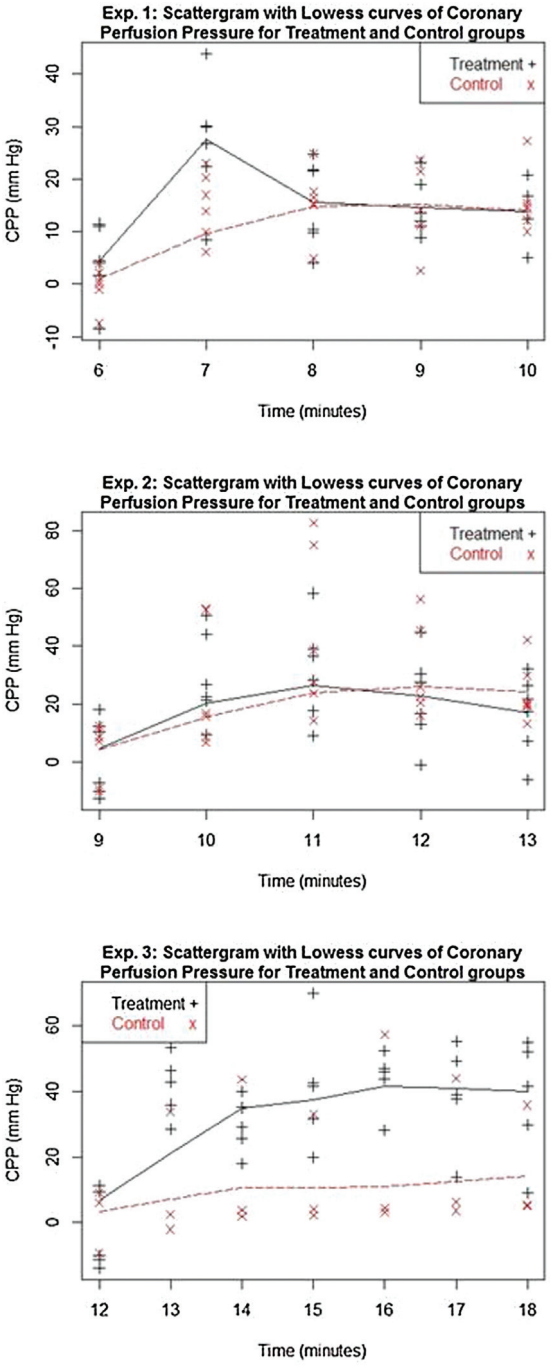


Fig. 3 – Scattergrams with Lowess curves of Coronary Perfusion Pressure (CPP) for Treatment and Control Groups in Experiments.1–3.

observed no consistent effect (Fig. 3), though over all animals and times prior to defibrillation at point D, CPP was 6.9 mm Hg (95% CI 2.1 to 12.2) higher in the treatment group.

It is hoped that a period of asystolic rest and possible chemical defibrillation may allow recovery of key myocardial substrates and minimize myocardial stunning, respectively, and these benefits could be reflected in post ROSC hemodynamics. Requirement for and time until norepinephrine were similar for the two groups across

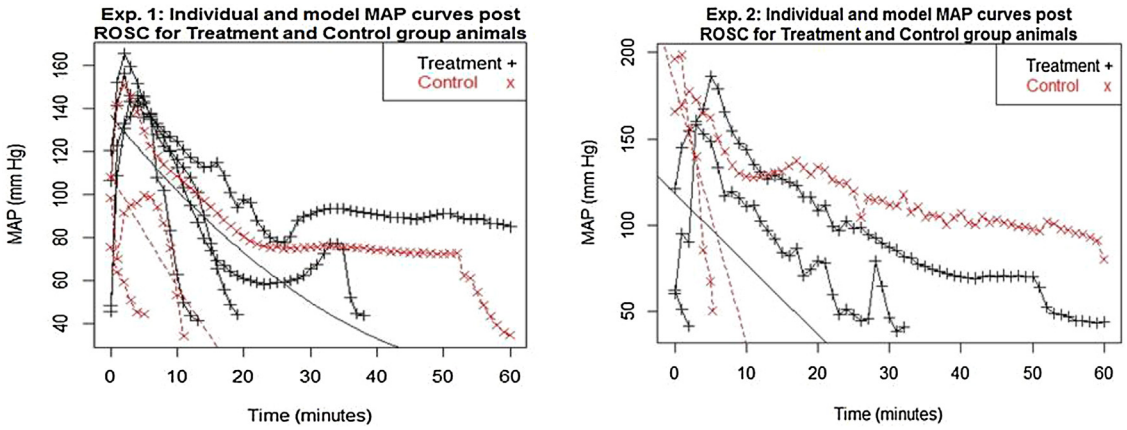


Fig. 4 – Individual and Model Mean Arterial Pressure (MAP) Curves Post ROSC for Treatment and Control Group Animals.

experiments one and two. Point estimates suggested mildly slower MAP decay post ROSC in the treatment groups, but this was not statistically significant.

Experimental group animals demonstrated a larger increase in pCO2 after potassium infusion during resuscitation (Table 2). This could be due to potassium exchange with hydrogen across cell membranes and bicarbonate buffering with increased CO2 production, more active metabolism in these animals that tended to have increased ROSC, or other unknown effects.

This series of experiments had multiple limitations including a limited number of animals with low power to detect a difference in outcomes, if such difference exists. Mixed linear regression analyses were used to minimize residuals and maximize power for comparisons of serial hemodynamic measurements, but these measurements are surrogate measures for myocardial perfusion and function. Multiple key outcomes such as survival are binomial. After 9 min of untreated VF, ROSC and survival were achieved in 4/6 experimental and 2/6 control animals. Given these point estimates, a power calculation suggests an experiment with minimum 33 animals in each group would be necessary to prove a statistically significant difference.

We were also limited in the factors that could be tested. For example, no changes in the dosing of calcium used to reverse plegia were made. Our model uses electrically induced VF in healthy young swine. This model has known benefits and weaknesses.[13]

Our results suggest that after minimal experimentation to determine an optimal therapeutic regimen, Kplegia is comparable to a recommended control regimen for the resuscitation of circulatory phase VF. A number of future directions are possible. It would be fascinating to perform an experiment with the necessary power as described above to test for a difference in survival. As performed, Kplegia relies on the presence of a peripheral vein catheter for drug infusion. This would likely be present in an in-hospital arrest, but not in the field. Kplegia may also be effective with intraosseous drug infusion, but this remains unknown. The resuscitation of patients with prolonged cardiac arrest is now benefiting from selective extracorporeal membrane oxygenation (ECMO) use. It is possible that a period of Kplegia during ECMO may benefit such recovering hearts.

Conclusions

We have found two regimens of Kplegia to be comparable to a contemporary control therapy in the resuscitation of electrically induced circulatory phase VF arrest. A Kplegia regimen with two higher doses of potassium was ineffective for resuscitation of metabolic phase VF arrest. Further experimentation is necessary to optimize and fully assess the potential benefit of this novel resuscitative strategy for VF arrest.

Conflicts of interest statement

None.

Disclosures

The LUCAS device that was used in this experiment was loaned to Dr. Menegazzi by Joilife. None of the authors have any financial interest in Jolife. The Zoll monitor-defibrillator that was used in this experiment was loaned to Dr. Menegazzi. None of the authors have any financial interest in Zoll. The authors have nothing else to disclose in relation to this particular investigation.

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