

Survival and neurological outcomes after nasopharyngeal cooling or peripheral vein cold saline infusion initiated during cardiopulmonary resuscitation in a porcine model of prolonged cardiac arrest*

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Objective: We have previously demonstrated that nasopharyngeal cooling initiated during cardiopulmonary resuscitation improves the success of resuscitation. In this study, we compared the effects of nasopharyngeal cooling with cold saline infusion initiated during cardiopulmonary resuscitation on resuscitation outcome in a porcine model of prolonged cardiac arrest. We hypothesized that nasopharyngeal cooling initiated during cardiopulmonary resuscitation would yield better resuscitation outcome when compared with cold saline infusion.

Design: Randomized, prospective animal study.

Setting: University-affiliated research laboratory.

Subjects: Yorkshire-X domestic pigs (*Sus scrofa*).

Interventions: Ventricular fibrillation was induced in 14 pigs weighing 38 ± 2 kg. After 15 mins of untreated ventricular fibrillation, cardiopulmonary resuscitation was performed for 5 mins before defibrillation. Coincident with the start of cardiopulmonary resuscitation, animals were randomly assigned to receive nasopharyngeal cooling with the aid of the RhinoChill Device (BeneChill, San Diego, CA) or cold saline infusion with 30 mL/kg

4°C saline. One hour after restoration of spontaneous circulation, surface cooling was begun with the aid of a water blanket in both groups and maintained for 4 hrs.

Measurements and Main Results: Jugular vein temperature significantly decreased in animals subjected to nasopharyngeal cooling in comparison with those receiving cold saline infusion ($p < .01$). Core temperature, however, decreased only in animals receiving cold saline infusion ($p < .01$). Coronary perfusion pressure was significantly higher in the animals treated with nasopharyngeal cooling ($p = .02$). All seven animals treated with nasopharyngeal cooling were successfully resuscitated in contrast to only two animals resuscitated in the cold saline infusion group ($p = .02$).

Conclusion: In this model, nasopharyngeal cooling initiated during cardiopulmonary resuscitation improved the success of resuscitation compared to cooling with cold saline infusion. (Crit Care Med 2010; 38:916–921)

KEY WORDS: cardiac arrest; cardiopulmonary resuscitation; hypothermia; ventricular fibrillation

Sudden cardiac arrest is a leading cause of death, with >300,000 victims in North America and approximately 700,000 in Europe every year (1, 2). More

than 50% of patients die before leaving the hospital, and the majority of deaths are attributed to postresuscitation myocardial dysfunction. Furthermore, approximately 30% of survivors exhibit permanent brain damage (3).

Experimental and clinical studies have demonstrated that hypothermia improves survival and long-term neurologic outcomes in cardiac arrest patients (4–7). Based on data from two of the largest randomized clinical trials (6, 7), the most recent American Heart Association Guidelines for Cardiopulmonary Resuscitation (CPR) recommend mild therapeutic hypothermia for all unconscious patients after cardiac arrest, specifically in the setting of ventricular fibrillation (VF) arrest (8).

It is now well-recognized that, to achieve the greatest benefit from hypothermia, cooling should be initiated as soon as possible after cardiac arrest (9). In an attempt to “move from defense to offense” (10), therapeutic hypothermia

initiated during CPR and before restoration of spontaneous circulation (ROSC) has also been shown in several recent studies to enhance outcome compared to initiation of hypothermia after ROSC (11, 12). This represents the so-called transition from therapeutic hypothermia to preservative hypothermia (9).

Current methods for inducing hypothermia have limitations when applied in out-of-hospital settings such that “preservative hypothermia” is difficult to achieve. Internal cooling is invasive and technically inadequate for field use (13, 14). Surface cooling with ice packs or cooling blankets is slow to reach target temperature. Peripheral vein cold saline infusion (CSI) started immediately after ROSC was shown to be an effective, safe, and feasible method for inducing hypothermia in resuscitated out-of-hospital cardiac arrest patients (5, 15). Some studies demonstrated that this method could be started during CPR (16), but the safety of large volumes of CSI for patients and

*See also p. 1006.

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Supported in part by BeneChill Inc., San Diego, CA.

This study was performed at the Weil Institute of Critical Care Medicine, Rancho Mirage, CA.

Dr. Denise Barbut is an employee of BeneChill Inc. The authors resident at the Weil Institute have not received, nor will they receive, any individual benefits other than academic recognition.

The other authors have not disclosed any potential conflicts of interest.

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DOI: 10.1097/CCM.0b013e3181cd1291

its efficacy in a pre-ROSC setting is still questionable. Nasopharyngeal cooling (NPC) is a feasible method for inducing hypothermia in out-of-hospital settings. Our previous studies have shown that NPC initiated during CPR significantly improves survival and neurologic outcome in porcine models of cardiac arrest (17–19).

In the current study, we sought to compare the outcome of CPR between hypothermia induced by NPC and peripheral vein CSI during CPR in a porcine model of prolonged cardiac arrest under mimicked prehospital settings. We hypothesized that NPC initiated during CPR would improve survival and neurologic outcomes compared with the peripheral vein CSI approach.

MATERIALS AND METHODS

This study was approved by the Institutional Animal Care and Use Committee of the the Weil Institute of Critical Care Medicine. All animals received humane care in compliance with the Principles of Laboratory Animal Care formulated by the National Society for Medical Research and *Guide for the Care and Use of Laboratory Animals* prepared by the Institute of Laboratory Animal Resources and published by the National Institutes of Health (NIH publication 0-309-05337-3, revised 1996). The animal laboratories of the Weil Institute of Critical Care Medicine are fully accredited by the American Association for Accreditation of Laboratory Animal Care International.

Animal Preparation

Fourteen male Yorkshire-X domestic pigs (*Sus scrofa*) weighing 38 ± 2 kg were utilized. Animals obtained from S and S Farms, Ramona, CA. Animals were fasted overnight except for free access to water. Anesthesia was initiated by intramuscular injection of ketamine (20 mg/kg) and completed by ear vein injection of sodium pentobarbital (30 mg/kg). Additional doses of sodium pentobarbital (8 mg/kg) were injected at intervals of approximately 1 hr to maintain anesthesia. A cuffed endotracheal tube was advanced into the trachea. Animals were mechanically ventilated with a volume-controlled ventilator (MA-1; Puritan-Bennett, Carlsbad, CA) with a tidal volume of 15 mL/kg and F_{iO_2} of 0.21. End-tidal P_{CO_2} was monitored with an infrared analyzer (01R-7101A; Nihon Kohden, Tokyo, Japan). Respiratory frequency was adjusted to maintain end-tidal P_{CO_2} (35–40 mm Hg). For measurement of mean aortic pressure, a fluid-filled 8-Fr angiographic catheter (6523; USCI C.R. Bard, Salt Lake City, UT) was advanced from the right femoral artery into the thoracic

aorta. For the measurement of right atrial pressure, pulmonary artery pressure, and pulmonary artery temperature (PAT) as core body temperature, a 7-Fr, thermodilution-tipped catheter (Abbott Critical Care 41216; North Chicago, IL) was advanced from the right femoral vein and flow-directed into the pulmonary artery. For inducing VF, a 5-Fr pacing catheter (EP Technologies; Mountain View, CA) was advanced from the right external jugular vein to the right ventricle. Another 5-Fr catheter was inserted for 7 cm in a retrograde fashion into right internal jugular vein for monitoring the retrograde jugular vein temperature, which previously was reported as an indicator of brain temperature (20, 21).

Experimental Procedures

Fifteen minutes before inducing cardiac arrest, PAT was adjusted to 38°C by using a heating lamp, warm packs, or ice packs. Cardiac arrest was induced by 1 mA alternating current through the fibrillation catheter. Mechanical ventilation was discontinued after onset of VF. At the end of 15 mins of untreated VF, CPR was started with chest compression using a pneumatic piston-driven chest compressor (Thumper, Model 1000; MI Instruments, Grand Rapids, MI). The animals were mechanically ventilated with 100% oxygen. Chest compression was programmed to provide 100 compressions per minute and synchronized to provide a compression-to-ventilation ratio of 30:2 with equal compression–relaxation intervals, i.e., a 50% duty cycle. The compression depth was adjusted to decrease the anteroposterior diameter by 25%. After 2 mins of CPR, the first 30 μ g/kg bolus of epinephrine was administered via the femoral vein. After 5 mins of CPR, a single 150-J biphasic electrical shock was delivered with a Heartstart XL defibrillator (Philips Medical Systems, Andover, MA). If an organized cardiac rhythm with mean aortic pressure of <60 mm Hg was observed or if VF

persisted, then CPR was resumed for 1 min before the next defibrillation attempt. Additional doses of epinephrine were given at 7 and 12 mins after the start of CPR until ROSC was achieved. An organized cardiac rhythm with a mean aortic pressure of >60 mm Hg, which persisted for an interval of 10 mins or more, fulfilled our criteria of successful resuscitation. Otherwise, resuscitation procedures were terminated after a maximum of another 10 mins.

After instrumentation, the animals were randomly assigned to the NPC or CSI group using the sealed envelope method. In both groups, the animals were cooled coincidentally with the beginning of CPR. In the NPC group, the pigs were cooled by the RhinoChill device (BeneChill) as we reported previously (17–19). In this study, the tubes were put into the nasal cavity and positioned to the nasopharynx. The coolant was delivered at 1 mL/kg/min by compressed oxygen at 1 L/kg/min. In the CSI group, ice-cold (4°C) saline (30 mL/kg) was infused continuously during CPR by an infusion pump (delivery rate = body weight mL/min) via a peripheral vein access at 4°C by placing the circulating tube inside a container with ice and ice-cold water before it was connected to the vein catheter. The NPC group was cooled for 60 mins based on our earlier investigation (18, 22). The CSI group was administered the infusion over 30 mins based on current clinical practice (5, 15). All the animals were then transitioned to surface cooling with a water-filled cooling blanket (CSZ Blanketrol II; Cincinnati SubZero Products, Cincinnati, OH). Surface cooling was discontinued 4 hrs after ROSC (Fig. 1). The 4-hr cooling interval was selected based on our previous experiments (17, 19).

After resuscitation, the animals were monitored in an intensive care setting (environmental temperature was maintained between 24°C and 25°C) for an additional 4 hrs and hemodynamics were obtained hourly during the observation period. Jugular vein temperature and PAT were obtained every minute un-

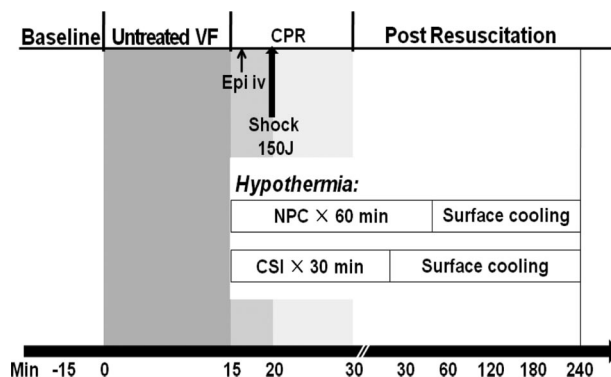


Figure 1. Experimental procedure. Fifteen minutes of untreated ventricular fibrillation (VF) was followed by 5 mins of cardiopulmonary resuscitation (CPR). Hypothermia was initiated with the start of CPR. NPC, nasopharyngeal cooling group; CSI, cold saline infusion group; BL, baseline.

til 30 mins after resuscitation, and then every 10 mins throughout the experiment. After the panel of 4-hr postresuscitation measurements and cooling procedure were completed, intravascular catheters were removed and wounds were surgically sutured. The animals were then rewarmed passively and returned into their cages and observed for an additional 92 hrs. Neurologic deficit scores (NDS) (23) were obtained daily during the 96-hr postresuscitation observational interval. The animals were then euthanized by injection of 150 mg/kg intravenous pentobarbital.

Measurements

The primary end point of this study was the success of initial resuscitation. Secondary end points included 96-hr survival and favorable NDS, total defibrillation success rate, total epinephrine dosage required for resuscitation, and coronary perfusion pressure (CPP).

A quantitative NDS developed by Berg et al (23) was used for evaluating neurologic injury at 24-hr intervals for a total of 96 hrs. In brief,

NDS consists of level of consciousness, motor and sensory function, respiratory pattern, and behavior. The neurologic deficits were scored from 0 (no observed neurologic deficit) to 400 (death or brain death). Two independent investigators measured the NDS in this study and reached agreement.

Hemodynamic data, including aortic artery, right atrial, and pulmonary artery pressures, end-tidal P_{CO_2} , and the lead II electrocardiographs were continuously measured and recorded on a personal computer-based data acquisition system, supported by CODAS (Computer Data Acquisition System, Cambridge, MA) as previously described (24). CPP was calculated from the difference in diastolic aortic pressure and coincident right atrial pressures. Left ventricular ejection fraction and fractional area changes were measured with the aid of Ultrasound System (Model HD11XE; Philips Medical Systems, Eindhoven, Netherlands).

Arterial blood gases were measured with a blood gas analyzer (Stat Profile pH0x;

NOVA Biochemical, Waltham, MA) adapted for porcine blood. Arterial blood lactate was measured with a lactic acid analyzer (model 23L; Yellow Springs Instruments, Yellow Springs, OH).

Statistical Analysis

The independent variable was the method of inducing hypothermia. Primary dependent variables are ROSC, jugular vein temperature, CPP, postresuscitation myocardial and cerebral function, and duration of survival.

Continuous values were presented as mean \pm SD or as medians and ranges. For binomial variables, Fisher exact test was used to compare initial success of resuscitation, and 96-hr survival was used to compare initial success between the two groups. Analysis of variance or the Mann-Whitney test was used to compare scale variables when appropriate. All the statistical analyses were performed with the use of SPSS version 14.0 (SPSS, Chicago, IL). For all statistical analyses, $p < .05$ was considered significant.

RESULTS

Baseline measurements did not differ significantly between the two groups (Table 1). There were no significant differences between groups after 15 mins of VF for both jugular vein temperature and PAT ($p = .12$; Table 2). After 5 mins of CPR and cooling, jugular vein temperature of the animals in the NPC group decreased by 1.8°C compared with only 0.3°C in the CSI group ($p < .01$), whereas the PAT of the animals in the CSI group decreased by 1.2°C compared with no changes in the NPC group ($p < .01$). The nasopharyngeal temperature of the animals in the NPC group rapidly decreased

Table 1. Baseline characteristics

	Nasopharyngeal Cooling (n = 7)	Cold Saline Infusion (n = 7)	p^a
Body weight, kg	38 \pm 2	38 \pm 2	.50
Pulmonary artery temperature, °C	38.0 \pm 0.0	38.0 \pm 0.0	.34
Jugular vein temperature, °C	38.0 \pm 0.1	38.0 \pm 0.1	.71
Mean aortic pressure, mm Hg	119 \pm 17	127 \pm 22	.24
Heart rate, beat/min	131 \pm 16	131 \pm 23	.48
Central venous pressure, mm Hg	7 \pm 1	7 \pm 1	.25
Cardiac output, L/min	7.2 \pm 0.8	7.3 \pm 1.4	.40
Left ventricular ejection fraction, %	66 \pm 3	66 \pm 3	.37
Fractional area change, %	36.5 \pm 2.2	36.1 \pm 1.9	.73
Arterial blood gas analysis			
PaO ₂ , mm Hg	101 \pm 6	98 \pm 14	.29
Base excess, mEq/L	6 \pm 2	7 \pm 2	.20
Lactate, mg/L	1.0 \pm 0.4	1.1 \pm 0.4	.33

^aBased on analysis of variance test as appropriate. Values are expressed as mean \pm SD.

Table 2. Temperature characteristics

	VF, 15 min	CPR, 5 min	PR, 30 min	PR, 60 min	PR, 120 min	PR, 180 min	PR, 240 min
Pulmonary artery temperature, °C							
NPC (n = 7)	38.3 \pm 0.1	38.3 \pm 0.1	36.6 \pm 0.6	36.2 \pm 1.0	35.4 \pm 1.5	34.9 \pm 1.0	34.6 \pm 0.6
CSI (n = 7)	38.2 \pm 0.1	37.0 \pm 0.5 ^a	36.6 \pm 0.2 ^c	36.7 \pm 0.5 ^c	35.4 \pm 1.0 ^c	34.3 \pm 1.0 ^c	34.1 \pm 0.1 ^c
Jugular vein temperature, °C							
NPC (n = 7)	38.1 \pm 0.2	36.3 \pm 0.7 ^a	35.6 \pm 0.8	35.1 \pm 0.9 ^b	35.8 \pm 1.8	35.2 \pm 1.3	35.2 \pm 0.7
CSI (n = 7)	38.0 \pm 0.2	37.7 \pm 0.4	36.6 \pm 0.6 ^c	36.9 \pm 0.1 ^c	35.9 \pm 1.6 ^c	35.1 \pm 1.1 ^c	34.8 \pm 0.4 ^c
Nasopharyngeal temperature, °C							
NPC (n = 7)	38.0 \pm 0.2	1.5 \pm 3.9 ^a	1.7 \pm 3.0 ^a	31.6 \pm 4.0	35.6 \pm 1.6	35.0 \pm 1.3	35.1 \pm 0.7
CSI (n = 7)	37.9 \pm 0.2	38.0 \pm 0.3	36.5 \pm 0.3 ^c	37.0 \pm 0.8 ^c	35.9 \pm 1.3 ^c	34.8 \pm 1.3 ^c	34.3 \pm 0.8 ^c

NPC, nasopharyngeal cooling; CSI, cold saline infusion; VF, ventricular fibrillation; PR, return of spontaneous circulation; CPR, cardiopulmonary resuscitation.

^a $p < .01$; ^b $p = .04$; ^cbased on $n = 2$. Values are expressed as mean \pm SD.

Table 3. Resuscitation outcomes

	Nasopharyngeal Cooling (n = 7)	Cold Saline Infusion (n = 7)	p
ROSC	7	2	.02*
Total shock success rate, %	75 (67–100)	21 (0–50)	<.01
Total epinephrine dose, $\mu\text{g}/\text{kg}$	30 (30–60)	90 (30–90)	.04
Cardiopulmonary resuscitation duration, secs	354 (298–420)	728 (300–900)	<.01

ROSC, restoration of spontaneous circulation.

*Based on Fisher exact test as appropriate. Non-normal distributive continuous variables presented as median with first and third quartiles (Q1–Q3).

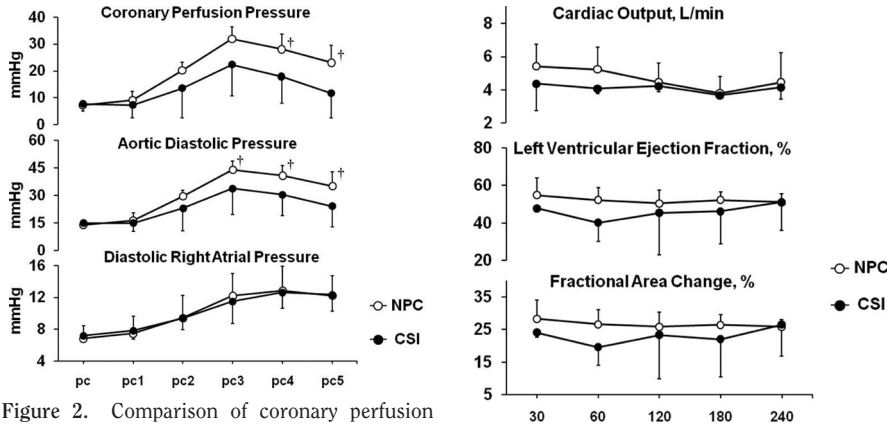


Figure 2. Comparison of coronary perfusion pressure, aortic diastolic pressure, and diastolic right atrial pressure values between the two groups during initial 5 mins of cardiopulmonary resuscitation. † $p < .05$. NPC, nasopharyngeal cooling; CSI, cold saline infusion.

to 1.5°C but remained at 38.0°C in the CSI group ($p < .01$).

All of the seven animals that received nasopharyngeal cooling were successfully resuscitated, whereas only two of the animals receiving the cold saline infusion were resuscitated ($p = .02$; Table 3). There was a higher success rate of overall defibrillation in the NPC group than that in the CSI group (75% vs. 21%; $p < .01$). The NPC group required significantly less epinephrine (30 $\mu\text{g}/\text{kg}$ vs. 90 $\mu\text{g}/\text{kg}$; $p = .04$) and shorter CPR duration (354 secs vs. 728 secs; $p < .01$) for resuscitation.

Thirty minutes after ROSC, jugular vein temperature was 2.4°C below the baseline value in the NPC group vs. 1.4°C in the CSI group; pulmonary artery temperature was decreased to 36.6°C in both groups. One hour after ROSC, jugular vein temperature was decreased by 2.9°C in the NPC group vs. 1.1°C in the CSI group ($p = .04$; Table 3). There were no significant differences between the two groups in jugular vein temperature, PAT, or nasopharyngeal temperature from 120 to 240 mins after resuscitation.

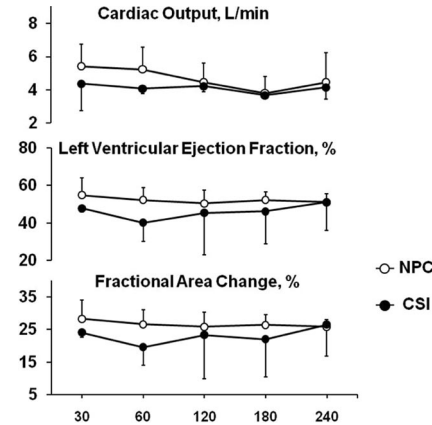


Figure 3. There were no significant differences of cardiac output, left ventricular ejection fraction, and fractional area change values at 30, 60, 120, 180, and 240 mins after resuscitation between the two groups. Nasopharyngeal cooling (NPC) group (n = 7); cold saline infusion (CSI) group (n = 2).

During the initial 5 mins of CPR, the CPP in the NPC group increased significantly from 7.3 to 23.0 mm Hg ($p = .02$), compared with from 7.8 to 11.8 mm Hg in the CSI group (Fig. 2). The aortic diastolic pressure of the animals in the NPC group was also higher than in the CSI group during CPR, increasing from 14.1 to 35.2 mm Hg in the NPC group but to only 15.0 to 24.1 mm Hg in the CSI group ($p = .03$). Diastolic right atrial pressure was not significantly different in the two groups. There were no significant differences in cardiac output, left ventricular ejection fraction, and fractional area changes at 30, 60, 120, 180, and 240 mins after resuscitation between the two groups (Fig. 3).

Four animals survived for 96 hrs in the NPC group; one of them completely recovered without neurologic deficit (NDS = 10). The other three animals that achieved ROSC in the NPC group died. One of those died after 36 hrs and the other two died 24 hrs after they had achieved ROSC. The two pigs that achieved ROSC in the CSI group also

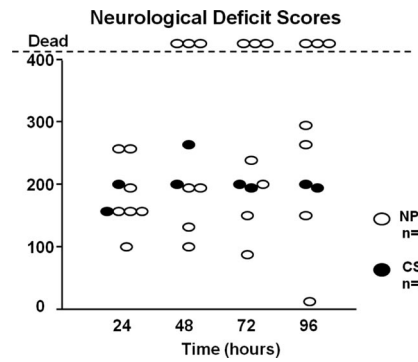


Figure 4. Neurologic deficit scores of all the resuscitated animals at 24, 48, 72, and 96 hrs after resuscitation. Score 0 means no observed neurologic deficit; score 400 means death or brain death. NPC, nasopharyngeal cooling; CSI, cold saline infusion.

survived for 96 hrs. The NDS values for all the animals are shown in Figure 4.

DISCUSSION

We have previously shown that when NPC was initiated during CPR, fewer electrical shocks, lower epinephrine dosages, and shorter CPR durations were required for resuscitation (17). NPC improves the resuscitation rate compared with normothermic controls both in a VF model (19) and a pulseless electrical activity model (25). We have also shown improved survival and neurologic outcomes in animals cooled nasally during CPR compared with those cooled using surface cooling initiated after successful resuscitation (18).

Clinically, peripheral cold saline infusion has been proved feasible for producing hypothermia in cardiac arrest survivors after resuscitation (15, 26) and experimental animals during CPR (16). However, CSI initiated during CPR has not yet been proved beneficial on resuscitation outcomes and its safety is still questionable.

In this study, CSI initiated at the start of CPR rapidly reduced PAT, as reported previously (16). However, at ROSC, the jugular temperature was scarcely lower than baseline after 5 mins of cold saline infusion. Conversely, in the NPC group, the jugular temperature was significantly decreased during CPR, whereas there were no changes in PAT. Therefore, we conclude that in current settings, intravenous saline was fairly effective at cooling the body but not the brain during the first 5 mins of CPR.

In the prolonged cardiac arrest model, nasopharyngeal cooling consistently improved resuscitation success (17–19, 22). We have also further demonstrated that a shorter duration of NPC was able to improve resuscitation success equivalent to a longer duration (22). For this study, we therefore preferred the NPC method for an interval of only 1 hr, and then we continued cooling with the external method. Again, in this model, NPC improved resuscitation success compared with peripheral cold saline infusion during CPR.

The mechanism by which NPC improves the resuscitation rate may be related to greater CPP during CPR (19, 25). The importance of achieving high CPP values for the success of the resuscitative effort is well-documented (27). In this study, we again documented that CPP increased significantly within 1 min of initiating NPC. This increase peaked at 3 mins of CPR and remained at this level immediately before the delivery of the first shock. CPP increases in the CSI group, however, were small and relatively short lived, and differences in CPP between the two groups was significant at 5 mins of CPR, even though the compression rate and depth were kept consistent in both groups.

Several studies have documented a decline in CPP after the administration of CSI (28). The reason for the negative impact on CPP might be volume loading an already ischemic right ventricle (29, 30), leading to an increase in right atrial pressure. However, this does not apply in the present study because there was no significant increase in right atrial pressure, but rather a rapid decrease in aortic diastolic pressure. The safety of the method of peripheral CSI initiated during CPR must still be proved by further studies.

The greater CPP during CPR in NPC animals was also observed in studies utilizing the 15-min cardiac arrest model (19, 25). However, the exact mechanism of the increase in CPP in the NPC animals is still unknown. The possible explanation may be that the cold-sensing neurons in the nasopharynx congregate on the preoptical region of the brain anterior to the hypothalamus. The response to temperature changes is channeled from these regions to neighboring cardiac autonomic control centers. Through these centers, the brain controls vasomotor tone in and around the heart (31).

We have previously shown and now reconfirmed that early NPC facilitates de-

fibrillation success (17, 18), represented by high defibrillation success rates, less epinephrine requirements and shorter CPR duration before ROSC. The mechanism is not just related to systemic hypothermia but rather to the head cooling itself, when achieved rapidly during CPR. When the head was cooled first, the animals were successfully resuscitated; however, when systemic temperature was decreased first by CSI, only a few animals achieved ROSC. The results also indicate as a possible mechanism the regional cooling of the cranial base. However, the significantly greater CPP during CPR and benefit for resuscitation observed in the NPC group in this study must be confirmed and extended in further studies.

In previous studies, NPC generated better neurologic and myocardial protective effects compared with normothermic conditions (17, 18). In the present study, however, after the animals achieved ROSC, both methods of inducing hypothermia decreased the core temperature effectively. There were no significant differences in myocardial function and 96-hr neurologic outcomes between the two groups. However, four animals in NPC group survived for 96 hrs and one of those completely recovered; only two animals that received CSI survived. A reason might be the more prolonged duration of VF, which was 15 mins in this study. Another explanation might be related to the head cooling level that the brain temperature achieved in this study. NPC was performed for 1 hr, and the brain temperature rarely decreased below 35°C. This may not be enough to warrant good cerebral protection. In our previous study, NPC continued for 4 hrs and the brain temperature was decreased to 32°C. This supports the conclusion that early rapid and effective head cooling yields beneficial neurologically protective effects. We might also speculate that an integration of the two methods of cooling, a rapid initiation of head cooling with NPC and continuation of systemic cooling with external methods, may be a better treatment. However, further investigations are anticipated to prove this hypothesis.

We recognize several limitations in the interpretation of our findings. The first is our inability to blind the investigators to the use of cooling methods during CPR attempts. This may potentially affect the CPR performance and produce false-positive findings. We attempted to account for this by using the established

setting of mechanical chest compression and ventilation rates. Another limitation is that we did not monitor the brain temperature directly; however, jugular vein temperature is regarded as a close indicator for the brain temperature (20, 21).

CONCLUSION

NPC initiated at the start of CPR significantly improved the resuscitation rate when compared with CSI in a porcine model of prolonged cardiac arrest.

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