Potential Use of Selective Aortic Arch Perfusion to Induce Profound Hypothermia as a Mechanism for Emergency Preservation and Resuscitation

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Introduction

- Hemorrhage is associated with greater than 90% of potentially surviavble deaths on the battlefield[1]
- The ultimate manifestation of such injuries, hemorrhage induced traumatic cardiac arrest (HiTCA), remains largely untreatable using current therapies[2]
- Emergency preservation and resuscitation (EPR) is a means of extending the window of organ viability and survival following HiTCA[3]
- Rapidly inducing profound hypothermia (<15°C core temperature) has been studied as a method to achieve this state of suspended animation, but involves techniques not practical for implementation on the battlefield[4]
- Selective Aortic Arch Perfusion (SAAP) employs a balloon-tipped catheter to deliver fluids directly to the aortic arch and coronary arteries while occluding distal vessels
- Implementing this SAAP technology to induce profound hypothermia via rapid fluid flush may make it preferable to other currently available hypothermic interventions due to its minimally invasive nature

Materials and Methods

- Yorkshire swine (40-60kg) were anesthetized, instrumented, and splenectomized
- Uncontrolled hemorrhage was induced via laparoscopic liver injury and exsanguination until carotid systolic blood pressure reached <10mmHg
- SAAP balloon was inflated, and chilled saline (6°C) was infused at 750mL/min
- Blood/saline mixture was recycled through the cooling circuit and a liver injury was performed
- The animal was left in a hypothermic state for one hour
- Cardiac, rectum, and brain temperatures as well as arterial blood pressures and carotid flow were continuously measured
- Rate of cooling as well as hemodynamic response were compared between experimental animals and data from previous studies

Experimental Overview

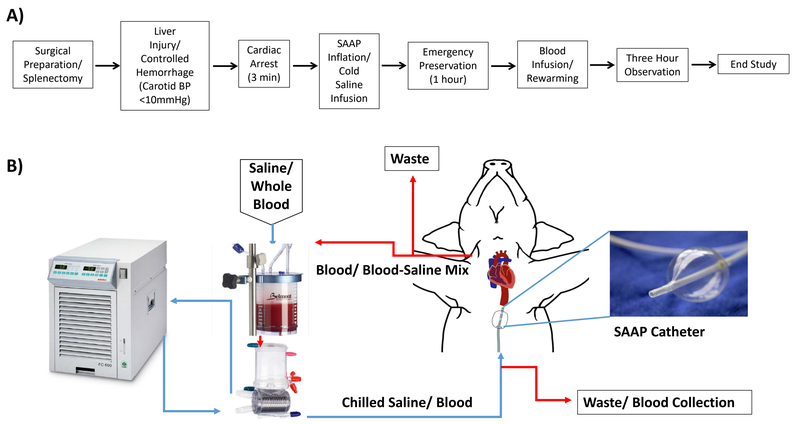

Figure 1. Experimental Overview
A) Flow diagram of the experimental procedures. **B)** Experimental setup overview. Blood was pulled through the SAAP catheter and saved for reinfusion. Saline recirculating in the heater-cooler was used to cool saline/ whole blood used for infusion. The infusion/draw rate was held constant at 750mL/min using a MasterFlex roller pump. The circuit did not recirculate until fluid drawn from the animal was adequately diluted and cooled.

Results

Overview

Table 1. Animal Overview

Animal	Weight (kg)	Saline Infused (L)	Spleen Weight (g)	Baseline MAP (mmHg)	Baseline Swan Temp (°C)	Baseline Brain Temp (°C)	Baseline Rectal Temp (°C)	Rate of Swan Cooling (°C/min)	Rate of Brain Cooling (°C/min)
9751	59	28	450	58	37.3	37.6	37.7	-3.17	-0.74
9752	53	30	410	71	38.2	38.6	38.5	-1.55	-0.24
9753	56	-	333	57	36.4	36.7	36.8	-3.32	-0.21
9754	50	23	341	58	35.7	36.0	36.0	-1.30	-0.85
9755	41	13	346	55	37.6	39.0	37.6	-2.48	-0.27
Average	52±7	24±8	376±51	60±6	37.0±1.0	37.6±1.3	37.3±1.0	-2.36±0.92	-0.46±0.31

Temperature

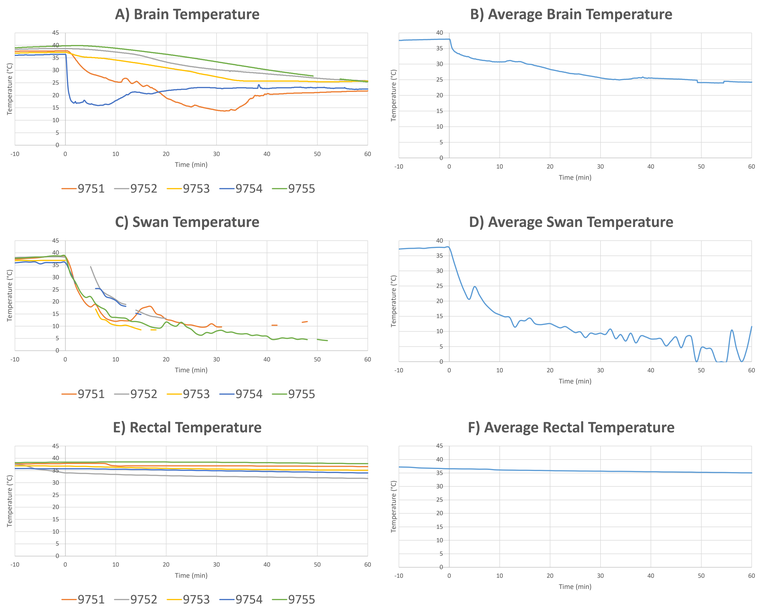

Figure 2. Brain, Swan, and Rectal Temperatures
T0 represents start of saline infusion. Prior to infusion, each animal underwent a laparoscopic liver injury followed by exsanguination until systolic blood pressure reached <10mmHg. The animal was monitored for 2 minutes post-liver injury prior to bleeding, and again for 2 minutes prior to infusion once systolic blood pressure<10mmHg. Injury and bleed times were variable among animals. **A)** Brain temperature was recorded autonomously for each animal via a probe inserted in the deep brain region. Data is shown for first 1 hour period post SAAP infusion. **C)** Swan-Ganz catheter was placed in the pulmonary artery for continuous temperature and pulmonary arterial pressure monitoring. Due to a technological inadequacy, swan temperatures were recorded by hand. **E)** Rectal temperatures were continuously monitored via a probe inserted in the anus

Angiography

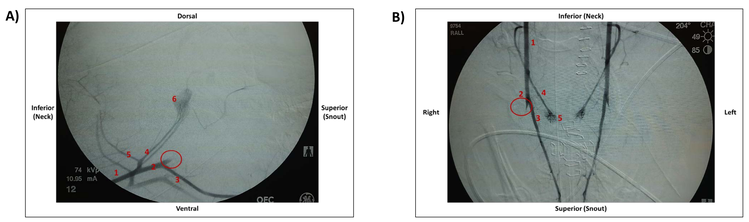

Figure 3. Angiography of Cerebral Vasculature
A) Prone position, Sagittal Plane. (1) Common Carotid Artery, (2) External Carotid Artery, (3) Linguinal Artery, (4) Ascending Pharyngeal Artery, (5) Occipital Artery, (6) Carotid Rete Mirabile. Note the vasoconstriction observed in the external carotid artery, just past the linguinal arterial branch. Image obtained from animal 9754 post-mortem

B) Prone position, Coronal Plane. (1) Common Carotid Artery, (2) External Carotid Artery, (3) Linguinal Artery, (4) Ascending Pharyngeal Artery, (5) Rete Mirabile. Note the vasoconstriction observed in the external carotid artery, just past the linguinal arterial branch. Image obtained from animal 9754 post-mortem

Results (cont.)

Hemodynamics

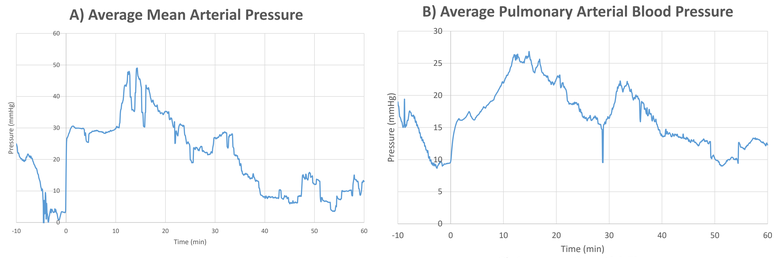

Figure 4. Hemodynamic Variables
All time points correspond to those indicated in Figure 2. **A)** Mean Arterial Pressure (MAP) was calculated from carotid arterial systolic and diastolic blood pressures continuously monitored via a Millar pressure sensor inserted in the carotid artery via percutaneous catheterization. **B)** Pulmonary arterial blood pressure was continuously monitored via the Swan Ganz catheter. Data validates that rapid fluid infusion was not resulting in damaging pulmonary hypertension. **C)** Fluid flow through the carotid artery was monitored continuously via a transonic flow probe placed on the carotid artery via cut-down. Addition of ultrasound gel between the probe and artery was used to prevent false flow readings.

Conclusions/ Future Directions

- Experiments still ongoing
- SAAP does not appear to be effective for rapid cooling of the brain
- Significant volume of fluid being lost in the abdomen, potentially in part due to the liver injury
- Cold fluid infusion may be causing vasoconstriction in the cerebral vasculature, rate of infusion not great enough to overcome blockage
- Technique for rewarming with autologous blood still needs to be optimized
- Future experiments will exclude liver injury groups and focus on feasibility of using SAAP for cold fluid infusion and cooling

References

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The views expressed here are those of the authors and do not necessarily reflect the official views or policy of the Department of the Defense or its components. The experiments reported herein were conducted according to the principles set forth in the National Institute of Health Publication No. 80-23, Guide for the Care and Use of Laboratory Animals and the Animal Welfare Act of 1966, as amended.