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Long-term consequences of abdominal aortic and junctional tourniquet for hemorrhage control

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ABSTRACT

Background: Specialized tourniquets have been deployed to the battlefield for the control of junctional/pelvic hemorrhage despite limited knowledge concerning their safety and duration of use. This study investigated long-term effects of abdominal application of the abdominal aortic and junctional tourniquet (AAJT) in a swine survival model.

Methods: Anesthetized spontaneously air-breathing swine were subjected to bilateral femoral artery injuries and subsequent 40% hemorrhage. Further hemorrhage was controlled by applying the AAJT on the lower abdomen for 0 h ($n = 2$, controls), 1 h ($n = 6$), 1.5 h ($n = 6$), or 2 h ($n = 3$). Before tourniquet release, arterial injuries were repaired, and mechanical ventilation and rapid crystalloid fluid were provided for at least 5 min. Additional fluid and 500 mL autologous blood were transfused after restoring blood flow. Animals were recovered and their mobility and health monitored up to 2 wk.

Results: AAJT application occluded the infrarenal abdominal aorta and stopped bilateral groin hemorrhage with rapid reversal of hemorrhagic shock and improved cranial blood pressure. All animals including controls recovered overnight but regaining hind leg function varied among AAJT-treated groups. In contrast to 1 h AAJT-treated swine that recovered full mobility in 1 wk, 2 h animals developed persistent hind leg paraplegia concurrent with urinary retention and ischemic necrosis of lumber muscles and had to be euthanized 3 d after surgery. Half of the 1.5-h group also had to be euthanized early due to paraplegia, whereas the other half recovered motor function within 2 wk.

Conclusions: The results of this animal study indicated that ischemic reperfusion injuries associated with abdominal application of the AAJT were time-dependent. To avoid permanent injuries, AAJT application on the abdomen to control a groin hemorrhage could not be longer than 1 h. This was consistent with recent instructions for application of this tourniquet on the abdomen in patients.

Introduction

During 10 y (2001-2011) of war in Iraq and Afghanistan, 19.2% of potentially survivable deaths were caused by hemorrhage from junctional wounds.[1] Such junctional injuries, particularly high extremity amputation, increased by 14-fold during this period and became more severe, disabling, and lethal than earlier conflict periods.[2]

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Current methods for rapid control of extremity hemorrhage involve applying limb tourniquets and covering the wound with hemostatic dressings and pressure bandages. However, the majority of hemorrhages caused by injuries at junctional sites such as groin, perineum, axilla, and neck are not amenable to limb tourniquet application or hemostatic treatment. In recent years, four specialized tourniquets were developed aiming to control hemorrhage from junctional injuries. One is the abdominal aortic and junctional tourniquet (AAJT) that is particularly suitable for the control of hemorrhage in victims of improvised explosive devices with high leg amputation and urogenital and pelvic injuries. To control hemorrhage from such injuries, the AAJT belt is tightly placed around the patient's lower abdomen, and its pneumatic bladder is inflated to generate sufficient pressure (300 mmHg measured by a pressure sensor) to deeply compress the abdominal wall. Such compression results in occlusion of underlying vessels including the abdominal aorta and inferior vena cava as well as collateral vessels beneath the tourniquet. The feasibility, effectiveness, and safety of abdominal application of AAJT were demonstrated in studies with healthy volunteers.[3,4] In these studies, the AAJT was applied only for a brief period (<5 min) to verify obstruction of blood flow in distal arteries and then released immediately.[3,4] AAJT application time to control hemorrhage in a trauma patient is likely to be much longer than a few minutes in a prehospital setting. To this end, longer application of AAJT and its consequences have not been tested on normal volunteers partially because it caused intolerable pain in some subjects.[5]

Our previous investigation of acute physiological effects of AAJT application in swine showed significant metabolic disturbances after release of AAJT, as well as histological changes in neural tissues that suggested possible disability in animals' hind legs.[6] Based on these premises, here we investigated the long-term consequences of abdominal application of the AAJT to control junctional hemorrhage in surviving swine. Our investigation tested the hypothesis that abdominal application of AAJT for the control of junctional hemorrhage is associated with some functional deficits.

Material and methods

Animals

This study was approved by the Institutional Animal Care and Use Committee of the U.S. Army Institute of Surgical Research. It was conducted in compliance with the Animal Welfare Act and implemented Animal Welfare Regulations. All animals received care and were used in accordance with the principles of *The Guide for the Care and Use of Laboratory Animals*.[7]

Yorkshire female cross-bred swine (4-6 mo old weighing 58 ± 4 kg) were purchased from Midwest Research Swine (Gibbon, MN) and housed for 1 wk to allow acclimation and a screening blood test for any pre-existing disease. Swine were subjected to fasting overnight before the surgery day with free access to water. On the day of surgery, swine were induced by an injection of tiletamine-zolazepam (Telazol, 4-8 mg/kg, intramuscularly) and initially anesthetized with isoflurane (3%-4%) via face mask to allow tracheal intubation. The intubated animals were then connected to the automatic anesthesia machine (Drager, Telford, PA) and allowed to spontaneously breathe a 30% oxygen-air mixture. Anesthesia was provided by continuous intravenous administration of Propofol (4-8 mg/kg/h) and Buprenorphine (2-10 μg/kg/h) for the rest of the experiment. The higher doses of these agents were administered to block any pain and discomfort caused by the application of AAJT. Five minutes before the release of the AAJT, their spontaneous breathing was transitioned to automatic ventilation (positive pressure) that was continued for the rest of the experiments. Maintenance fluid (Lactated Ringer's, [LR]) was administered intravenously (IV) at 5 mL/kg/h through a marginal ear vein. Body temperature was monitored and maintained at 37°C-38°C. A cefazolin antibiotic injection (1 g in 10 mL) was given IV before the start of surgery.

Surgical procedures

The right common carotid artery was percutaneously cannulated to monitor and record vital signs (systolic, diastolic, mean arterial pressure [MAP] and heart rate) and to perform controlled hemorrhage. The external jugular vein was also percutaneously cannulated for infusion of resuscitation fluid. Next, ~10 cm incisions were made in both groin areas and ~3 cm segments of the femoral arteries were isolated. These vessels were clamped with microvascular clamps and partially transected (50% of circumference in the middle using iris scissors). The AAJT was then placed loosely around the lower abdomen and prepared for pressurization, as previously described.[6]

Next, pigs were subjected to hemorrhage by following two steps: first, 500 mL blood (~25 mL/min) was collected from the carotid artery (controlled hemorrhage) in a blood bag and saved for autologous transfusion at a later time; second, an uncontrolled hemorrhage was conducted by removing the clamps from the femoral arteries and allowing free bleeding (uncontrolled hemorrhage) up to ~40% of the original total blood volume of each swine (estimated as 7% of body weight). Further blood loss was prevented by rapidly inflating the AAJT bladder with sufficient pressure (about 300 mmHg) to stop hemorrhage in both legs. The groin wounds were then covered with gauze and occasionally inspected to ensure that no rebleeding occurred. The AAJT was applied on three groups of swine (n = 3-6/group) for 1-h, 1.5-h, or 2-h period, respectively. Following AAJT application, a small volume of Hextend (up to 500 mL) was infused IV to some animals as needed to raise and maintain their blood pressure at baseline levels during AAJT application. This latter infusion was done to eliminate any potential adverse effects of prolonged hypotension during AAJT application and in control animals. During the last 15 min of AAJT application, injured arteries were flushed and repaired by primary suturing (6-0 Prolene). Control animals ($n = 2$) were also subjected to 40% controlled and uncontrolled hemorrhage, but bleeding was controlled by clamping the injured femoral arteries that were subsequently surgically repaired. The AAJT was also loosely placed around the abdomen of control swine for 1 h but it was not pressurized. Five minutes before release of the AAJT, positive pressure ventilation and rapid IV fluid administration (500 mL LR