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Intraintestinal drainage as a damage control surgery adjunct in a hypothermic traumatic shock swine model with multiple bowel perforations

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ABSTRACT

Background: Temporary bowel ligation (TL) has been proposed to prevent contamination as a damage control procedure in multiple bowel perforations. However, bacteria translocation and intestinal ischemia may develop in a prolonged duration. We here hypothesized that intraintestinal drainage combined with temporary ligation (D-TL) would decrease intestinal injury and improve survivals in a gunshot multiple bowel perforation swine model in the setting of a damage control surgery.

Materials and methods: The abdomen was shot one time with an experimental modified gun whereas pigs were hemorrhaged to a mean arterial pressure of 40 mm Hg and maintained in shock for 40 min. Cold lactated Ringer solution was gradually infused to induce hypothermia. Animals were randomized to primary anastomosis, TL and intraintestinal D-TL groups ($n = 8$). Animals were resuscitated for 12 h with the shed blood and lactated Ringer solution. Delayed anastomosis was performed in TL and D-TL animals after resuscitation. Surviving animals were humanely killed 24 h after operation. Systemic hemodynamic parameters were recorded and blood samples were obtained for biochemical assays. Intra-abdominal pressure, portal vein and peripheral vein bacterial cultures, small intestine hematoxylin-eosin staining, and transmission electron microscopy examination were performed at 0, 2, 6, 12, and 24 h after the surgery.

Results: All animals suffered extreme physiologic conditions as follows: hypothermia, severe acidosis, hypotension, and depressed cardiac output. Compared with the primary anastomosis and TL group, D-TL animals required less resuscitation fluid, suffered a lower intra-abdominal hypertension and bacterial translocation, normalized lactate levels faster, had lower serum creatine kinase, aspartate aminotransferase levels and tissue TNF-α level, and nuclear factor-kB activations and thus had greater early survival.

Conclusions: Compared with primary intestinal anastomosis and TL, rapid bowel ligation combined with intraintestinal drainage as a damage control adjunct improved survivals in a multiple bowel perforation swine model in the setting of damage control surgery.

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1. Introduction

Damage control surgery (DCS) offers a simple alternative to the traditional surgical management of complex or multiple injuries in a critically injured patient. DCS includes a staged approach consisting of an initial operation, intensive care unit resuscitation, and planned reoperation [1,2]. However, best efforts at resuscitation and operation often lead to a lethal cascade of events, including metabolic acidosis, hypothermia, and coagulopathy—termed the "lethal triad of death". Although control of bleeding is the major component of DCS, the effects of rapid methods of control of spillage of the bowel and rapid closure of the abdomen have not been experimentally evaluated [2–4].

Extensive repair of complex traumatic injuries in these patients are hazardous. Olofsson *et al.* [5] demonstrated that early rapid control of multiple bowel perforations after high-energy trauma resulted in less impairment of cardiovascular function than conventional resection anastomosis of the bowel. Our team previously successfully developed a hypothermic traumatic shock swine model of multiple bowel injuries mimicking abdominal gunshot-induced bowel perforations [6]. Furthermore, we demonstrated that temporary rapid bowel ligation was preferred to primary intestinal anastomosis because it diminished operative time, led to reduced resuscitation volume requirements, accelerated clearance of lactic acid, maintained stable hemodynamics, and improved early survival rate. Furthermore, the relationship between the time course limit of temporary rapid bowel ligation, ligation leading to obstruction-related bowel injury, and intensive care unit resuscitation time needs to be better characterized in additional experiments. Based on our clinical experiences, intestinal obstruction and bacterial translocation may develop if the duration of bowel ligation extends, which may subsequently induce sepsis and multiple organ dysfunction. Inspired by tube ileostomy [7–9], we assumed that intraintestinal drainage by inserting the tube through the disrupted bowl ends may decrease the intraintestinal pressure and thus minimize the systemic inflammatory response. In this study, we aim to investigate the effects of intestinal ligation combined with tube drainage on the intestinal mucosal barrier and systemic inflammatory response compared with simple ligation, in the setting of multiple bowel injuries.

2. Materials and methods

2.1. Preparations

The Animals Research Council of Jinling hospital for the care and use of laboratory animals approved the study. Female domestic pigs, with a mean body weight of 26.4 kg (range 24.5–30.2 kg) were used in the study after a 5- to 7-d acclimatization. After an overnight fast with water *ad libitum*, swine were premedicated with ketamine (20 mg/kg) and atropine (0.06 mg/kg). After endotracheal intubation, the animals were ventilated mechanically. Animals were maintained and anesthetized with intravenous injection of 150 mg/kg/min propofol (Disoprivan 2%, emulsion; AstraZeneca, Wedel, Germany) and bolus injection of 2–5 mg/kg fentanyl (Janssen Cilag, Neuss, Germany). The ventilation was adjusted to maintain $PaCO_2$ of <40 mm Hg. Oxygen supplementation was given to maintain an arterial oxygen saturation of 97%. After preparation, a 5-Fr flow-directed thermodilution triple-lumen catheter (Arrow International Inc, Reading, PA) was inserted into the pulmonary artery through the right jugular vein. An angiocatheter was placed in the carotid artery and mean arterial pressure (MAP) was transduced. All the ends of these catheters were tunneled subcutaneously, exteriorized between scapulae, and secured. A 12-Fr Foley catheter was inserted in the urinary bladder. Gastrostomy was also done for gastrointestinal decompression. After instrumentation, animals were allowed to equilibrate for a period of 15 min, and baseline measurements were obtained.

2.2. Hypothermic traumatic shock animal model

A hypothermic traumatic shock swine model with multiple bowel perforations, mimicking traumatic shock, was used in this study, as described previously [6].The first step is the gunshot. The anesthetized animals were kept in a right lateral position and shot in the abdomen one time with an experimental-modified gun (bullet diameter of 7.62 mm, rate of fire of 250–260 m/s), causing a penetrating abdominal wound. The inlet of the bullet was 20 cm above the symphysis pubis and 10 cm from midline and the firing range was 40 cm. Controlled hemorrhage shock was performed immediately after the gunshot. Animals immediately underwent a standardized, controlled hemorrhage by withdrawing blood from the jugular artery until an MAP of 40 mm Hg was reached. We gradually infused 4°C lactated Ringer solution (10 mL/kg) through the jugular vein catheter to induce hypothermia during hemorrhage shock. The infusion rate was constrained to be slow to avoid cardiac decompensation [10].

MAP was maintained at this level for 40 min by withdrawing or reinfusing shed blood, to simulate delay in arrival of prehospital personnel. Blood was collected in blood donation bags with citrate phosphate preservative and then placed at 4°C on an orbital shaker for later reinfusion. Net weight was recorded to estimate the volume fraction of hemorrhage.

Permissive hypotension resuscitation was simulated at prehospital stage for 4 h, as previously described. Pigs were resuscitated with lactated Ringer solution until the MAP reached 60 mm Hg. This procedure simulated prolonged hypotensive resuscitation before reaching the hospital or the operating room, keeping systolic blood pressure >80 mm Hg or MAP >60 mm Hg [11]. Epinephrine was infused if MAP dropped below 40 mm Hg.

The in-hospital stage was then performed. All animals were closely monitored in the animal intensive care unit with a propofol micropump infusion for sedation and analgesia. Vital signs, urine output, and systemic hemodynamic parameters were periodically recorded. Shed blood was reinfused and hypothermia was carefully corrected by airway heating and humidification, raising ambient temperature above 28°C, and covering the animal with surgical drapes and