Use of an epidural cooling catheter with a closed countercurrent lumen to protect against ischemic spinal cord injury in pigs

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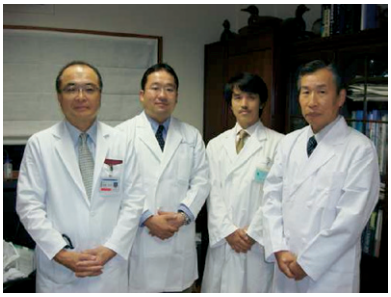

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Objective: We developed an epidural cooling catheter containing cold saline solution circulating in an isolated lumen. After placement by a minimally invasive approach, we evaluated protection effect against ischemic spinal cord injury in pigs.

Methods: Fourteen pigs underwent thoracic aortic double clamping for 45 minutes under systemic mild hypothermia (36°C). Group A (n = 7) underwent local hypothermia with the cooling catheter. Group B (n = 7) underwent catheter placement only, without cooling. Spinal cord somatosensory evoked potentials were recorded to assess electrophysiologic status. Neurologic function was evaluated with a modified Tarlov score.

Results: At aortic crossclamping, spinal temperature in group A (26.5°C ± 2.4°C) was significantly lower than that in group B (35.3°C ± 0.6°C, $P = .0001$). Mean time from aortic crossclamping to onset of potential loss was significantly longer in group A (28.4 ± 6.6 minutes) than in group B (18.3 ± 5.0 minutes, $P = .007$). Mean duration of total loss of potentials was significantly shorter in group A (19.0 ± 6.7 minutes) than that in group B (31.3 ± 5.9 minutes, $P = .003$). Group A showed significantly better neurologic function (mean Tarlov score 4.4 ± 0.8) than that of group B (0.1 ± 0.4, $P = .0001$). Mean total number of intact motor neurons was significantly greater in group A (24.5 ± 6.8) than that of group B (9.9 ± 6.8, $P = .0001$).

Conclusion: By cooling the spinal cord selectively and continuously, the newly designed epidural cooling catheter prevented ischemic injury in a pig model of aortic crossclamping.

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Paraplegia has remained a devastating problem associated with thoracoabdominal aneurysm repair. Reported incidence of this complication ranges from 5% to 8% in advanced centers.[1-4] Numerous surgical and pharmacologic interventions have been proposed for prevention, but no single method has succeeded completely in avoiding this dreaded complication.

Systemic hypothermia is a protective measure used frequently against paraplegia associated with aortic surgery.[5-7] It carries, however, risks of coagulopathy, pulmonary dysfunction, and cardiac arrhythmia.

Regional hypothermia would be a logical alternative approach to minimizing adverse effects of systemic hypothermia while preserving its merits.[8] Cambria and colleagues[9] reported a method of regional cooling involving infusion of iced saline solution into the epidural space, demonstrating that infused iced saline solution without drainage from the epidural space could cool the spinal cord selectively. This method raised the major concern of possible associated eleva-

Abbreviations and Acronyms
sSEP = spinal cord somatosensory evoked potential

tion in cerebrospinal fluid pressure, however, which would worsen spinal cord perfusion.[10]

In a previous experimental study, we examined the effectiveness of epidural cooling against spinal cord ischemia by simply placing a U-shaped catheter containing cold circulating saline solution in the epidural space.[11] This protocol required two large skin incisions (70 mm) and open laminectomy to permit catheter introduction, however, making the procedure too invasive for clinical use.

To overcome this problem, we developed a new cooling catheter with a closed countercurrent lumen. This less cumbersome catheter could be placed with only minimal invasiveness. We investigated its cooling ability and protection against ischemic injury in pigs.

Materials and Methods

All animals received humane care and treatment in accordance with the "Guide for the Care and Use of Laboratory Animals" (www.nap.edu/catalog/5140.html). Further, both the experimental and animal care protocols were approved by the Animal Care Committee of Saitama Cardiovascular and Respiratory Center, Osatogun, Japan.

Epidural Cooling Catheter and Continuous Cord Cooling System

The basic concept of our cooling system has been reported previously.[11] In this study, saline solution was cooled externally to 4°C and circulated at a constant rate of 45 mL/min by an external pump (AST Co, Ltd, Higashimatsuyama, Japan). Instead of placing a loop catheter bent at the midpoint to form a U shape, we developed a special catheter with a closed countercurrent lumen. This polyurethane cooling catheter (Unitika, Tokyo, Japan), with a 16-gauge outer diameter and 25 cm length, had a lumen in which cold saline solution could circulate without leakage (Figure 1). The coolant entered the inlet limb of the cooling catheter, passed through the full length of the lumen, and then turned back at the tip of the catheter to be returned to the external units.

Surgical Preparation, Catheter Installation, and Cooling Protocol

A total of 14 adult pigs weighting 35 to 40 kg were used. The animals were randomly divided into two equal groups, a regional hypothermia group with cold saline solution circulating through the epidural cooling catheter (group A) and a control group with catheter placement but no circulating cold saline solution (group B).

Swine were anesthetized initially with intramuscular ketamine (15 mg/kg), intubated, and placed in a right lateral decubitus position on a cooling-warming blanket to maintain mild systemic hypothermia (36°C). Anesthesia was maintained with 2.0% isoflurane added to a mixture of 50% oxygen and 50% nitrous oxide.

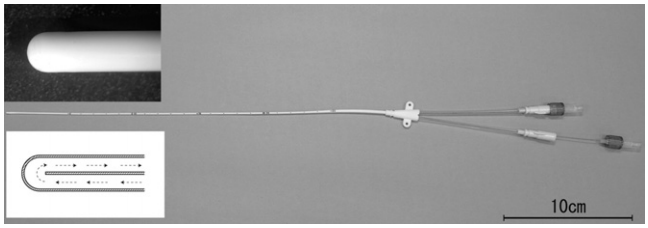

Figure 1. Epidural countercurrent cooling catheter. Saline solution circulates in isolated lumen of cooling catheter, reversing flow direction at tip of catheter without epidural leakage.

A 30-mm vertically oriented incision was made 10 mm lateral to the midline at the level of L3. According to a minimally invasive technique used in orthopedics (METRx-MD; Medtronic Sofamor Danek, Minneapolis, Minn), the caudal part of the superior lamina and the ligamentum flavum were exposed.[12] Partial caudal hemilaminectomy and removal of the ligamentum flavum were performed to provide entry for the tip of the epidural cooling catheter. Under fluoroscopic guidance, the catheter was advanced carefully into the dorsal epidural space in a cephalad direction until the tip reached the level of Th6. Proximal epidural temperature, distal epidural temperature, and spinal temperature were recorded continuously with thermistor probes placed upon the dorsal dura at Th5 and L4 and in the subarachnoid space at L4. An intrathecal pressure sensor (Johnson & Johnson, Raynham, Mass) was introduced into the subarachnoid space by means of needle puncture at the L5-L6 interspace.

Left thoracotomy was performed at both the fourth and seventh interspaces. Systemic anticoagulation was provided with heparin sulfate (6-U/kg intravenous bolus). Pressure monitoring catheters were inserted into the right axillary artery, the middle portion of the crossclamped descending thoracic aorta, and the right femoral artery for recording of arterial pressures proximal, central, and distal to the aortic crossclamp, respectively. In both groups swine underwent thoracic double aortic crossclamping for 45 minutes distal to the origin of the left subclavian artery and also just above the diaphragm (Figure 2). During aortic crossclamping, proximal hypertension was controlled with nicardipine hydrochloride (4 μg/kg as bolus), After aortic unclamping, blood pressure was restored with phenylephrine hydrochloride (3 μg/kg as bolus).

Group A animals underwent epidural cooling with the cooling catheter, beginning 30 minutes before aortic crossclamping and continuing during the 45 minutes of aortic crossclamping. After clamp release, epidural cooling was continued for 30 further minutes to slow the rise of spinal temperature accompanying reperfusion (total epidural cooling 105 minutes). In group B, the epidural catheter was placed in the same fashion, but swine did not undergo epidural cooling at any point in the procedure. After surgery, pigs were extubated and returned to cages with free access to water and food.