

Echo-guided Identification of Key Lumbar Arteries for the Spinal Cord: Preliminary Study in the Canine Model

Kazumasa ORIHASHI¹⁾, Hajime KUMAGAI¹⁾, Mitsuhiro ISAKA¹⁾, Koji ARIHIRO²⁾
 and Taijiro SUEDA¹⁾

1) Department of Surgery, Division of Clinical Medical Science, Graduate School of Biomedical Sciences, Hiroshima University, Hiroshima 734-8551 Japan

2) Department of Anatomical Pathology, Hiroshima University Hospital, Kasumi 1-2-3, Minami-ku, Hiroshima 734-8551 Japan

ABSTRACT

Although identification of the key artery that perfuses the spinal cord is essential to avoid occurrence of paraplegia after surgery on the thoracoabdominal aorta, reliable and noncomplicated measures are not yet available. A new method of determining it by using echocardiography with a saline injection into the lumbar artery was evaluated for feasibility and adequacy in a canine model. In two mongrel dogs, the abdominal aorta was opened and saline was directly injected into the lumbar arteries while the spinal cord was visualized by echocardiography through the intervertebral disc. When the echogenic or Doppler signal was detected in the spinal cord, the particular lumbar artery was determined as "positive", or as "negative" when the signal was not detected. After the dog was sacrificed, red resin was injected into the "positive" arteries and blue resin into the "negative" arteries. In the extracted spinal cord, the anterior and posterior spinal arteries were filled with red resin, rather than with blue resin, to indicate that the key arteries were correctly identified. There were multiple "positive" arteries, which were mainly located on the left side and accounted for approximately one-third of the entire lumbar arteries. The "negative" arteries mainly perfused the muscles around the vertebra. Injected resin came out of the adjacent lumbar arteries of the same category, suggesting that communication is present among the positive arteries, but independently of that among the negative arteries. Echo-guided identification of key arteries is technically feasible and correctly determines the key arteries in this preliminary canine model.

Key words: Spinal artery, Echocardiography, Spinal cord ischemia, Adamkiewicz artery

Identification of the intercostal artery (ICA) or lumbar artery (LA), which mainly perfuses the anterior spinal artery, i.e., the artery of Adamkiewicz, is one of the most important issues in thoracoabdominal aortic surgery to avoid an occurrence of postoperative paraplegia. It is reported to arise from the ICA/LA between T8 and L1 in 70 to 80% of patients and from the left side in 70 to 80% of cases^{1,10}. However, this is the result of statistical analysis and does not tell the surgeon which artery is to be preserved in a particular patient. Although surgeons presume that the large ICA/LA has to be reconstructed, Koshino et al. reported that the Adamkiewicz artery does not necessarily originate from the larger artery⁶. There has been a number of attempts to visualize the Adamkiewicz artery preoperatively by using angiography, computed tomography, or magnetic resonance imaging^{5,7,11}. However, it can be visualized only in 70% of patients^{7,11}. Even if the Adamkiewicz artery is identified by these modalities, surgeons often hesitate to sacrifice every

other ICA/LA based on these data.

Recently motor-evoked potentials (MEP) are more popularly used to determine if the clamped segment of the aorta leads to the Adamkiewicz artery³. Although MEP diagnosis is reported to be accurate⁴, it is based on the change of potentials caused by ischemic insults on the spinal cord. It takes time to obtain the results and may cause irreversible damage of the spinal cord during the ischemic period. To solve this problem, Sueda et al. infused cold blood into the clamped segment of the aorta to accelerate the MEP changes as well as to reduce ischemic damage of the spinal cord by topical cooling⁸.

These methods, however, necessitate preoperative preparations and may be unfeasible in emergency cases with unstable hemodynamics. We need measures that are able to relate each ICA/LA to the spinal cord perfusion and which are available in the operating room without complicated prearrangements.

Codet et al²⁾ reported that the spinal cord could

be visualized by means of transesophageal echocardiography (TEE) through the intervertebral disc. Voci et al⁹⁾ showed that the anterior spinal artery could be visualized with TEE. Unfortunately, Doppler assessment of blood flow in this artery is difficult because of its nearly perpendicular course to the ultrasonic beam, and this is a critical limitation of this method. Thus, there has been no report of the successful application of this technique for aortic surgery. Instead, we have devised an alternative method of identifying the key ICA/LA by detecting the signal in the spinal cord following an injection of saline into the ICA/LA. The purpose of this study is: 1) to evaluate the feasibility and adequacy of this method in a canine model as a preliminary step; and 2) to elucidate the problems to be solved toward the clinical use of this technique.

MATERIALS AND METHODS

Animals received humane care in compliance with the "Principles of Laboratory Animal Care" formulated by the Institute of Laboratory Animal Resources and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources and published by the National Institute of Health.

Two adult mongrel dogs weighing from 9.0 to 11.0 kg were used. After the dog was premedicated with intramuscular atropine sulfate (0.5 mg), anesthesia was induced with an intramuscular injection of ketamine hydrochloride (0.3 ml/kg). Endotracheal intubation was facilitated with the

intravenous administration of thiamylal sodium (15 mg/kg) and pancronium bromide (0.05 mg/kg). General anesthesia was maintained with isoflurane (1.5–2.0%) carried by O₂ (2 liters/min) under volume-controlled mechanical ventilation.

With the dog in the right decubitus position, the abdomen was opened laterally and the abdominal aorta was exposed from the diaphragm level to the bifurcation. The spinal cord was visualized using a 5MHz biplane transesophageal echocardiographic probe for pediatric use (SSD-870, UST-5246S-5, Aloka Co., Tokyo, Japan). The echo probe was placed perpendicularly to the vertebral column and the spinal cord was scanned through the intervertebral disc (Fig. 1) with a transducer for longitudinal scanning. The spinal cord was examined at two different levels where it was clearly visualized: at the upper lumbar level (L1 to L2 level) and at the lower lumbar level (L4 to L5 level). In the short-axis view of the spinal cord, the anterior spinal artery was depicted at the anterior aspect of the spinal cord (Fig. 2A). In the pulsed-wave Doppler mode, a sampling volume (2 to 5 mm in length) was placed on the anterior portion of the spinal cord.

The dog was exsanguinated and the abdominal aorta was incised longitudinally along the left anterior wall and the orifices of LAs were identified. While the spinal cord was depicted and the blood flow signal was recorded, 1 to 3 ml of saline was injected into each LA.

The accuracy of this echo assessment was evaluated by the resin casting method. Injecting type

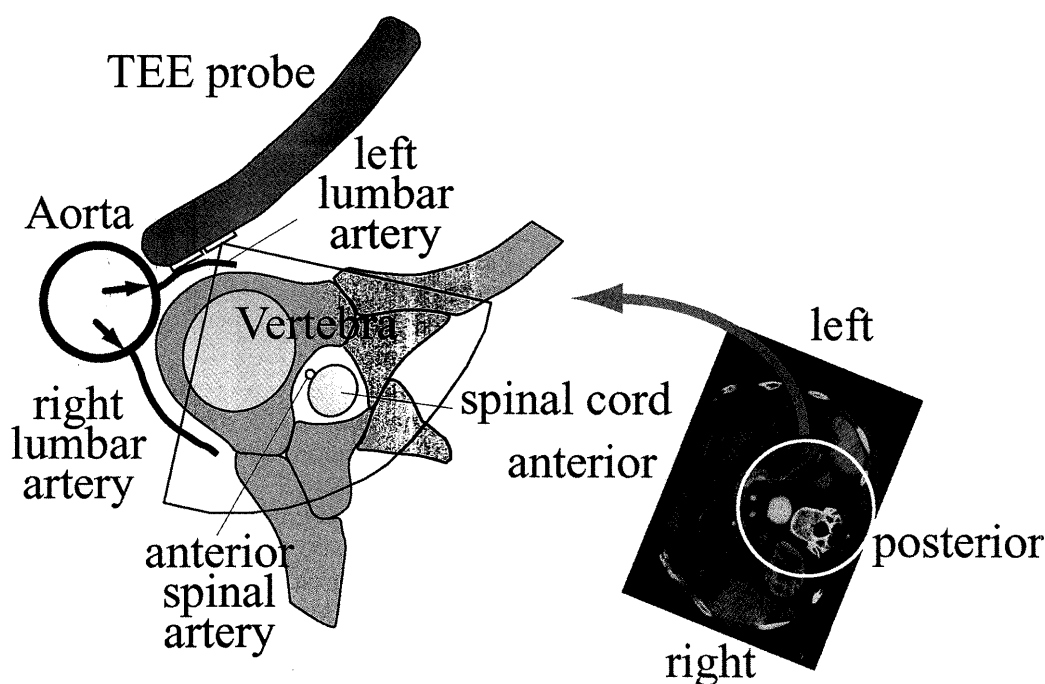


Fig. 1. Schematic illustration demonstrating the method of visualizing the spinal cord.

A transducer for longitudinal scanning was placed on the vertebra and the spinal cord was scanned through the intervertebral disc. The aorta was opened later and saline injected into the lumbar arteries (arrow).

resin (MERCOCX, CL Series, Oken-Shoji, Tokyo, Japan) was prepared for injection into the LAs by adding 0.1 g of catalyst to 5 g of acrylic casting material to start polymerisation. Because the sclerosing process starts within a few minutes and is completed within 5 min after mixture, the resin was injected within a few minutes of preparation. In the first dog, red resin was injected into the positive LAs and then blue resin into the negative LAs. In the second dog, blue resin was injected into the negative LAs, then red resin into the positive LAs. If the echo assessment has correctly identified the real positive LAs, the spinal arteries should be filled with red resin irrespective of the order of injection.

After the dog was sacrificed, the lumbar vertebrae and spinal cord were eviscerated en bloc. The spinous processes and laminae were removed and the spinal canal was opened. The spinal cord was carefully extracted while cutting the nerve roots. The anterior and posterior aspects of the spinal cord were visually inspected to ascertain whether the spinal cord was filled with red or blue resin. The spinal cord was then fixed in 10% formalin solution and embedded in paraffin for light microscopic observation. A tissue section was stained with Hematoxylin & Eosin stain.

RESULTS

The spinal cord was clearly visualized at the upper and lower lumbar levels by means of 5MHz echocardiography by placing a transesophageal probe perpendicularly to the vertebral column and scanning through the intervertebral disc with a

transducer for longitudinal scanning (Fig. 1). Although it was a new technique for visualizing the spinal cord to place an echocardiographic probe perpendicularly to the vertebral column with a transducer for longitudinal scanning, it was helpful for successful visualization in a limited space. The anterior spinal artery could be depicted in a B mode image (Fig. 2A). As 1 to 3 ml of saline was injected directly into each LA after aortotomy, a Doppler signal was apparently detected in the anterior portion of the spinal cord (Fig. 2D) or an echogenic dot appeared in the anterior spinal artery (Fig. 2B) and moved into the spinal cord parenchyma (Fig. 2C). Because the dog had been exsanguinated before saline injection, these signals were likely to be generated by the saline injected into the collapsed vessels in the spinal cord. When the Doppler signal appeared in pulsed-wave Doppler mode immediately following saline injection (Fig. 2 D) or echogenic dots appeared in the spinal cord (Fig. 2 A to C), this particular LA was determined as a "positive LA". If neither of these findings was present, it was determined as a "negative LA". The series of saline injections was repeated, while the spinal cord was visualized at the other level. Each LA was determined as either "positive" or "negative" based on the results of these two series of saline injections. Echo findings were apparent when saline was injected into the positive LAs that were close to the level of scanning for visualizing the spinal cord, whereas they were often unclear when injected from the distant LAs. Eight and eleven LA orifices were found in the first and second dog, respectively. Each LA

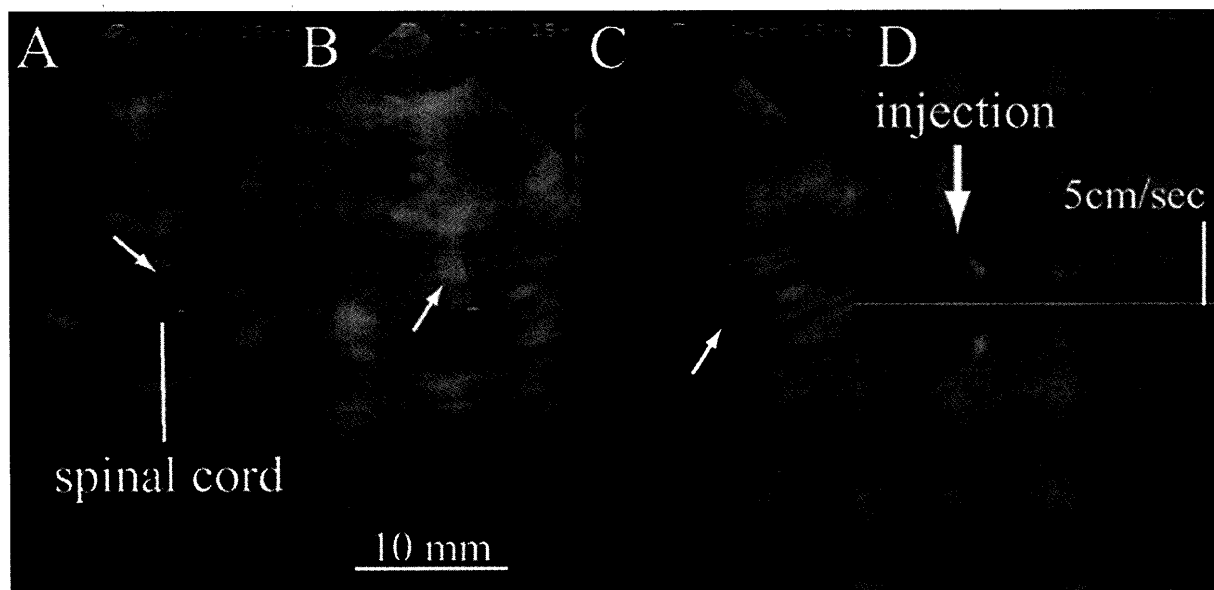


Fig. 2. Echo images of the spinal cord in short axis and its changes after saline injection.

A: spinal cord with anterior spinal artery (arrow) in the spinal canal. The sampling volume is placed on the anterior portion of the spinal cord. B: an echogenic dot (arrow) appeared in the anterior spinal artery following saline injection. C: an echogenic dot (arrow) moved into the spinal cord parenchyma. D: Doppler signal detected following saline injection.

was distinctly determined as either a "positive LA" or "negative LA" based on the presence or absence of echo signals following saline injection, respectively. Three of eight LAs (37.5%) were "positive" in the first dog and 4 of 11 LAs (36.4%) were "positive" in the second dog; all of these positive LAs were situated on the left side. Among the four pairs of LAs found in the first dog, the first, third, and fourth left LA were positive. There were four right LAs and 7 left LAs in the second dog. The second, fourth, fifth, and seventh left LA were positive.

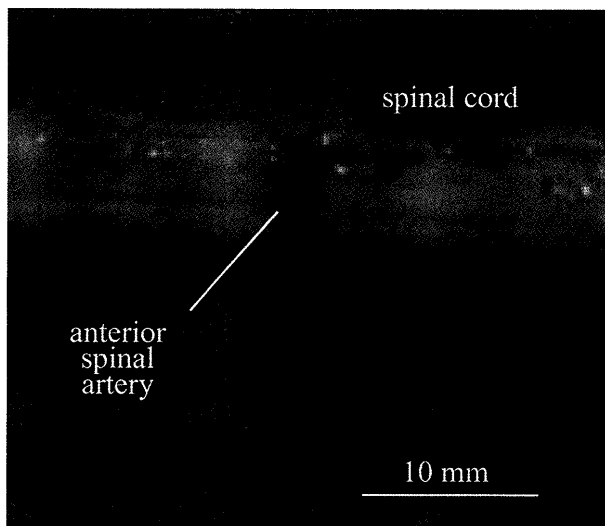
When red resin was injected into the positive LAs, it came out of the adjacent positive LAs but not from the negative LAs. Similarly, when the blue resin was injected into the negative LAs, there was a backflow of blue resin from the adjacent negative LAs but not from the positive LAs. The presence of communication among the positive LAs and also among the negative LAs was suspected. They appeared to be independent of each other. When a backflow was present, the ori-

fice of the LA was manually obliterated to minimize stealing of the resin.

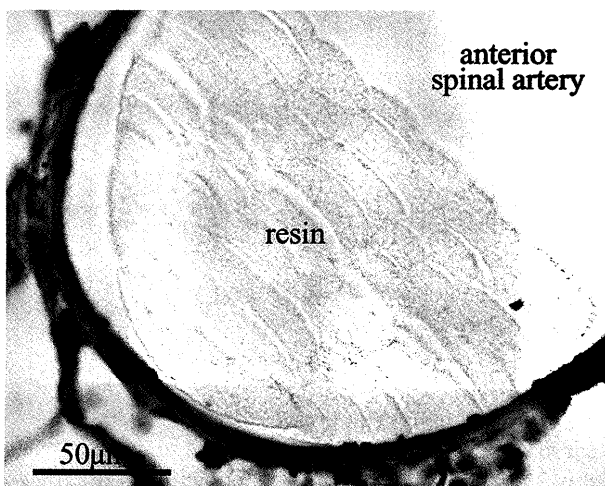
In the extracted spinal cord, one anterior spinal artery and two posterior spinal arteries were found to be filled with red resin in both dogs (Fig. 3A). If the "positive" LA was falsely diagnosed as "negative", blue resin would enter the spinal artery. However, blue resin was not found in any portion of the spinal cord. In the first dog, it was possible that the red resin injected first into the correctly diagnosed "positive LA" could have occupied the lumen of the spinal artery and subsequent entry of blue resin been interrupted. Thus, a false negative result could have been masked. To avoid this error, blue resin was injected first into the "negative LAs" in the second dog prior to an injection of red resin into the "positive LAs". While the spinous process and lamina were being removed, blue resin was often found in the muscles around the vertebrae. Microscopic observation also showed that red resin occupied the spinal arteries (Fig. 3B, C).

DISCUSSION

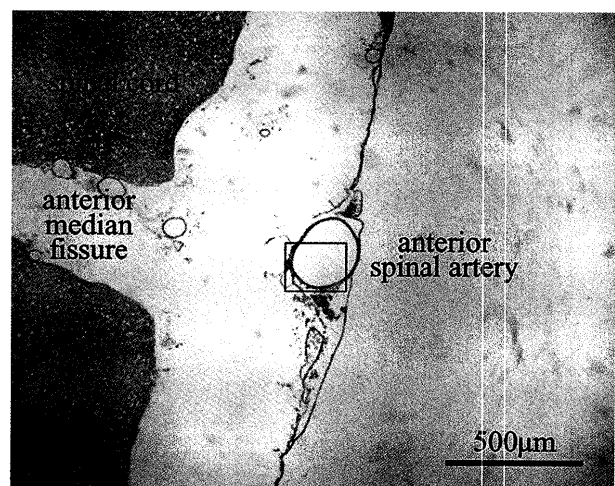
The results of this study can be summarized as follows: 1) the LAs which perfuse the spinal cord could be correctly identified by detecting the Doppler signal or echo contrast in the spinal cord following saline injection; 2) the "positive LA" was not single, but there were multiple "positive LAs"; 3) the positive LAs were mainly located on the left side and accounted for approximately one-third of all LAs; 4) the "negative LAs" mainly perfused the



A



C



B

Fig. 3. Spinal cord after resin injection.

A: macroscopic appearance of anterior aspect of the spinal cord. Red resin is present in the anterior spinal artery. B: Anterior portion of the spinal cord with anterior spinal cord (H&E, $\times 40$). C: Anterior spinal artery (magnification of square in B; $\times 400$). The lumen of the anterior spinal artery is filled with resin (H&E, $\times 400$).

muscles around the vertebrae; and 5) the steal phenomenon of injected resin indicated the presence of communication among positive LAs independent of that among negative LAs.

Our method proved to be technically feasible and correctly identified the LAs which perfuse the spinal cord in the canine model. The echo findings were discrete enough to determine whether a particular LA was "positive" or "negative". Before this study, we considered that the use of echo contrast agent was essential and that it actually generates clear signals. However, an injection of echo contrast media into the artery is not approved. Instead, saline injection generated an apparent echo signal in both B mode and pulsed-wave Doppler mode, probably because saline contains a small amount of bubbles which cause a strong echo or because an injection of saline temporarily increases the blood flow velocity in the spinal artery. Such echogenic dots resemble those detected in the cardiac chambers following intravenous injection of drugs or transfusion. Because there were no apparent bubbles in the injected saline and air embolism was not noted in the microscopic examination, those dots are unlikely to cause adverse effects, although careful manipulation is mandatory when injecting saline.

The accuracy of echo diagnosis for determining each LA as either "positive" or "negative" was confirmed by the results of the resin casting method. The echo-determined "positive LAs" proved to perfuse the spinal cord whereas the "negative LAs" perfuse not the spinal cord but the muscles around the vertebrae. Although the positive LAs could be mistakenly identified as negative, the alternated order of injecting the two resins ruled out this error.

In these two dogs, there was no single LA which exclusively perfused the spinal cord but rather a group of LAs communicated with each other and perfused the spinal cord. Communications were also present among the negative LAs, but separate from those among the positive LAs. These results provide a new surgical strategy of preserving the perfusion of the spinal artery: a few positive LAs are preserved while the remaining positive LAs and all negative LAs are sacrificed. However, positive LAs do not necessarily perfuse the anterior spinal artery directly but narrowly through communication among positive LAs. This could be a pitfall when this method is applied to clinical practice. Further investigation is obviously necessary to clarify if the same rule is applicable in humans.

Limited space around the vertebrae makes it difficult to place an echo probe in a proper position and to direct the transducer correctly to the spinal cord, especially when aortic aneurysm occupies a large space in the surgical field. A conventional echo probe occupies a large space and its use may interfere with the injection of saline into the LAs.

We found that a pediatric transesophageal probe is small enough and the transducer can be properly placed. Another approach for visualizing the spinal cord is to scan it from the esophagus through the intervertebral disc as reported by Godet et al²⁾ and Voci et al⁹⁾, although it is difficult in the canine model for anatomical reasons.

It should be noted as a pitfall, however, that detection of the Doppler signal becomes unclear when the spinal cord is examined at a level distant from the LA into which saline is injected. This may lead to a false negative result. The detection of the signal needs to be checked carefully at at least two levels of the spinal cord.

In this study, saline was infused after the blood was exsanguinated. In a clinical setting, however, collateral circulation may interfere with the entry of saline into the spinal arteries. Saline injection under an aortic clamp without exsanguination needs to be examined as the second step of this canine study.

In conclusion, this preliminary study showed that the echo detection of echogenic or Doppler signals following saline injection is technically feasible and correctly and distinctly identifies the LAs that perfuse the spinal cord.

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