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Basic Experiment on Thoracoscopic Aortic Cross-Clamping as an Alternative to Resuscitative Thoracotomy

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Abstract

Background: Aortic Cross-Clamping (ACC) via Resuscitative Thoracotomy (RT) is performed in patients with haemorrhagic shock not only to control bleeding, but also to redistribute the limited blood volume to the coronary and cerebral arteries. In chest injury, RT, including clamshell thoracotomy, is inevitable because haemostasis and repair of damaged organs are simultaneously required. On the other hand, RT with AXC to control bleeding for intra-abdominal injury is considered to be excessively invasive.

Objective: This basic experiment explored the possibility of a minimally invasive "thoracoscopic AXC".

Method: This experiment was conducted in accordance with the Declaration of Helsinki and the animal experiment guidelines of the author's institute. A Large Yorkshire pig (female) weighing 44.5 kg was placed under general anaesthesia (1% to 2% isoflurane) and a thoracoscope was inserted through the left intercostal space. Approaching the posterior mediastinum along the left chest wall, the descending aorta was identified and completely clamped with the inserted AXC forceps. The difficulty of the procedure, total time until clamping, and problems encountered during the procedure were recorded.

Results: The approach to the posterior mediastinum was relatively easy, but cross-clamping to the intended position took some time due to obstruction by the pulmonary ligament. The total time from insertion of the thoracoscope to completion of AXC was 3' 58" with no significant change in the pig's vital signs. The insertion ports of the thoracoscope and the AXC forceps had to be separate.

Conclusion: Although the acquisition of skills to directly and rapidly reach the descending aorta, including setting the insertion points of the thoracoscope and the AXC forceps, is a significant problem, this experiment revealed that this procedure is anatomically feasible. However, since in humans the lung and the pulmonary ligament may hinder the approach to the posterior mediastinum, repeated training may be necessary to shorten the maneuvering time. In addition, development of a device integrating the thoracoscope and AXC forceps might be necessary.

Keywords: Aortic cross-clamping; Resuscitative thoracotomy; Haemorrhagic shock; Severe trauma

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Background

In lethal severe trauma, haemorrhage and brain injury are still the main causes of death. Patients with brain injury frequently suffer from the difficult situation of returning to society even after life-saving treatment, but for those with exsanguinating haemorrhage, the possibility of survival and return to work would be higher if rapid haemostasis and fluid resuscitation are achieved.

Aortic Cross-Clamping (ACC) has long been used as a measure for bleeding control in devastating haemorrhage cases [1-4]. Cardiac arrest and secondary brain damage might be avoided by saving time in completing haemostasis and enabling a limited blood volume to supply the coronary and cerebral arteries [5,6]. Several reports have demonstrated the survival of patients who underwent RT for abdominal injury, and in these cases, it was inferred that bleeding control by AXC was successful [7-9].

In chest injury, RT, including clamshell thoracotomy, is inevitable because haemostasis and repair of damaged organs are simultaneously required. On the other hand, RT combined with

Figure 1: Two ports were placed on the left chest to insert a thoracoscope and hand instrument.

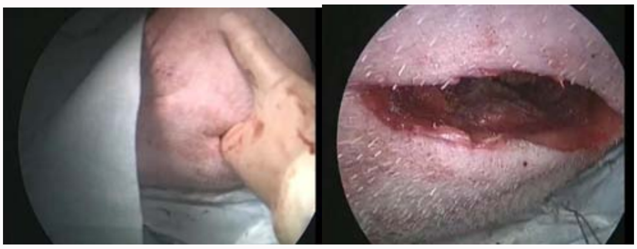

Figure 2: A small open thoracic incision was made just sufficiently large to insert three fingers, in order to insert AXC forceps.

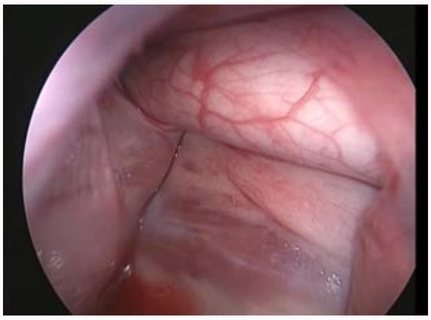

Figure 3: The descending aorta was identified behind the pulmonary ligament (arrow).

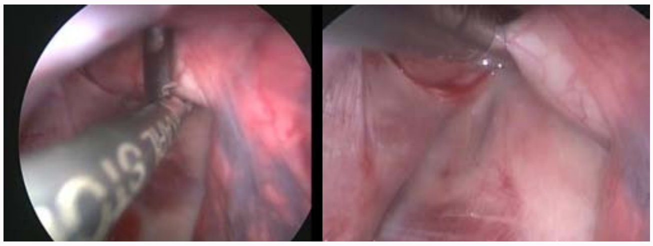

Figure 4: AXC by the hand instrument via the port. It was easier than using AXC forceps, but since the hand device is small relative to the diameter of the human aorta, there is a high possibility that the tip of the instrument could slip from the aorta.

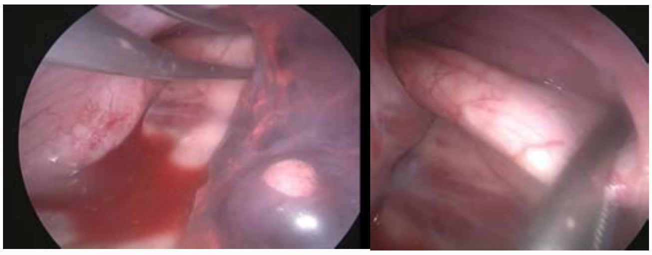

Figure 5: Using AXC forceps via the open thoracic wound. The time until clamping using AXC forceps was prolonged because of obstruction by the lung ligament, but strong clamping was achieved by large forceps.

AXC to control bleeding in intra-abdominal injury is regarded as an excessively invasive manoeuvre. Approach to the descending aorta can be made quickly and reliably via RT, when there is no adhesion in the thoracic cavity, however, performing RT in the case of extra thoracic injuries is equivalent to adding an AIS (abbreviated injury score) of 3 of chest trauma, which must be a significant invasion to the patient. In fact, after the improvement of hemodynamics, bleeding from the chest wound of RT sometimes persists, requiring repeated thoracotomies and excessive use of blood transfusion. Therefore, to maintain the effects of AXC and to overcome its weak points, a basic experiment was conducted to explore the possibility of a minimally invasive "thoracoscopic AXC" procedure.

Materials and Methods

This experiment was conducted in accordance with the Declaration of Helsinki and the animal experiment guidelines of the author's institute. A Large Yorkshire pig (female) weighing 44.5 kg was intubated with administering 4.0 ml of pentobarbital after 24-hr fasting and placed under general anaesthesia (1% to 2% isoflurane). Anaesthesia was maintained with 2% isoflurane and muscle relaxant, and a vital sign was monitored intraoperativelybya pulse oximeter and electrocardiograph.

Two ports for inserting a thoracoscope and hand instrument for aortic clamping were placed on the left chest (Figure1). Separately from those ports, a small open thoracic incision, just large enough to insert three fingers, was made to insert AXC forceps (Figure 2). A thoracoscope (IMAGE 1 HD Camera, KARL STORZ SE & Co. KG, Tuttlingen) was inserted through one port. By approaching the posterior mediastinum while observing the diaphragm on the left along the chest wall, the descending aorta was identified behind the pulmonary ligament (Figure 3). Next, complete aortic clamping was carried out with the inserted hand instrument (Endo Grasp TM, COVIDIEN JAPAN Inc., Tokyo) via another port or with the AXC forceps (Cooley's aortic forceps, AESCULAPInc., USA) through the open thoracic incision. The difficulty of the procedure, total time until clamping, and problems encountered during the procedure were recorded.

Results

Through the thoracoscopic view, the field of operation in the thoracic cavity was sufficiently secured, and visibility of the posterior mediastinum was not problematic. The approach to the posterior mediastinum was relatively easy, but cross-clamping to the intended position took some time due to obstruction by the pulmonary ligament.

It took roughly one minute to install two ports and conduct a small thoracotomy, respectively. The same procedure was performed twice, and the time from insertion of the thoracoscope to completion of AXC by the hand instrument was 2' 50" the first time and 1' 25" the second time (mean: 2' 08") (Figure 4). At this time, since the hand device was sufficiently large relative to the diameter of the porcine aorta, there was no possibility that the tip of the instrument could slip from the aorta. The time needed to clamp using the AXC forceps was 3' 38" the first time and 4' 14" the second time (mean: 3' 58"), and strong clamping was achieved with large forceps (Figure 5).

There was no significant change in the pig's vital signs during the procedures. The insertion port of the thoracoscope and the AXC forceps had to be separate.

Discussion

The implementation of AXC in trauma treatment was first reported by Ledgerwood et al. [1]. AXC is an ultimate measure for controlling haemorrhage and avoiding cardiac arrest in response to subdiaphragmatic trauma, such as intra-abdominal injury or unstable pelvic fracture, and is a dynamic procedure of considerable interest to young doctors. However, patient conditions requiring AXC are extremely serious, and AXC alone is notable to achievehaemostasis, and the patient will not survive if bleeding after AXC does not stop. Therefore, reports on the effect of AXC have not always been favorable. This can also be inferred from many articles reporting emergency department thoracotomy [10-12].

AXC sometimes achieves a dramatic result even if encompassing several disadvantages. For example, spinal cord injury during clamping and reperfusion injury after decamping are the most common complications. The pathophysiologic condition for these complications has been studied by many experiments [13-16], but clinically preventive treatment has not yet been established. Since these may coexist with AXC implementation, a "trade-off" between the effect of AXC and complications must be considered when performing AXC.

Apart from this issue, bleeding from the chest wall caused by thoracotomy is another important complication of AXC. In RT under unstable hemodynamics such as impending cardiac arrest, bleeding from the opened chest wall is usually not regarded as a problem at that time. However, when the circulation improves after the effect of AXC, it may be difficult to stop bleeding, especially, from the dissected part of the latissimus dorsi muscle deeply cut dorsally in order to widely secure the thoracic cavity. This means that an invasion equivalent to AIS of 3 of chest trauma is added by RT for AXC and should be avoided especially with the concomitant complications of AXC.

Therefore, the possibility of thoracoscopic AXC was investigated in order to implement "minimally invasive AXC" for extra thoracic injury with impending cardiac arrest. Flaris et al. [17] investigated RT enforcement time (skin to control of the heart wound) using human cadavers [17], but no studies have examined the time to AXC implementation. In this respect, we believe there is novelty in this experiment. In this experiment, it was possible to carry out thoracoscopic AXC in a relatively short time. However, based on our experience, considering that a well-trained surgeon or emergency physician can perform AXC via RT in around one minute, it can be concluded that thoracoscopic AXC remains an inferior procedure. Although quick cross-clamping was achieved in this experiment, this could be attributed to the small diameter of the porcine descending aorta which could be easily clamped with standard thoracoscopic forceps. Accordingly, use of this device with the human aorta, which has a large diameter, might not be appropriate. For this reason, a dedicated larger device will be necessary for human use.

The manoeuvring time of thoracoscopic AXC must be shortened further for this method to be practical. The time to reach the descending aorta along the thoracic vertebrae initially was an anatomical and technical issue, but it is possible that the time required for this procedure is likely to decrease along with an increasing degree of proficiency. Another concern was whether it is possible to approach the descending aorta while successfully avoiding the left lung. The porcine thorax is smaller than that of the human and it was easy to approach in this experiment, but in humans the distance from the chest wall to the posterior mediastinum is considerable, so the expanding lung could become a barrier to approaching the descending aorta. Clamping using Cooley's aortic forceps was unequivocal. However, the greatest challenge was obstruction by the lung ligament to clamping the aorta, which prolonged the time until the completion of clamping using AXC forceps. This anatomical problem could be resolved by changing the direction in which the AXC forceps are inserted. In addition, the fact that the thoracoscope and the AXC forceps had to be inserted separately into the thoracic cavity complicated the procedure and prolonged the time to complete AXC. If a dedicated device can be developed to integrate the thoracoscope and the guide way of the forceps, it would enable the insertions to be conducted at the same position. In humans, conducting a smaller thoracotomy by eliminating the need to make ports to insert both a thoracoscope and forceps would shorten the manoeuvring time.

In recent years, the emergency medical system of dispatching physicians to the scene and providing medical treatment has been established. London's Air Ambulance is actively implementing RT in a prehospital setting and our facility also conducts prehospital thoracotomy [18-22]. Thoracoscopic AXC may be a more effective measure in the prehospital scene where bleeding for extrathoracic haemorrhagemust be controlled with less equipment and a short treatment time.

Limitations of this research were as follows. Firstly, because it was a porcine experiment, it was difficult to evaluate the ease of the anatomical approach to the thoracic descending aorta in humans. Secondly, since it was a trial of an unusual procedure, it was not possible to conduct a quantitative evaluation using many animals from the viewpoint of animal protection.

Conclusion

In order to develop minimally invasive AXC against severe subdiaphragmatic injury involving fatal haemorrhage, the possibility of thoracoscopic AXC was investigated using animal experiments. However, in humans the lungs may hinder the approach to the posterior mediastinum, hence repeated training may be necessary to shorten the manoeuvring time. In the future, human trials should be conducted, including the development of specialized devices integrating the thoracoscope and AXC forceps.

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