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Optimizing the dissection of small-diameter pulmonary vessels using vessel-sealing systems

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Title: Optimizing the dissection of small-diameter pulmonary vessels using vessel-sealing systems

Running Head: Optimizing vessel dissection using vessel-sealing systems

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ABSTRACT

Background Although vessel-sealing systems have been shown useful for dissection of small-diameter vessels, no studies to date have evaluated the optimal angle of dissection.

Methods Lateral thermal damage to a canine pulmonary artery was assessed microscopically. Burst pressure was compared in swine carotid arteries undergoing orthogonal and oblique dissections to determine the safer dissection technique.

Results Histological analysis of a canine model revealed a thermal spread of approximately 1.3 mm. Burst pressure comparison showed no significant differences between orthogonal and oblique dissection angles (829.2 mmHg~~N~~ [range 608–1214 mmHg~~N~~] vs. 949.1 mmHg~~N~~ [range, 593–1306 mmHg~~N~~], P = 0.206).

Conclusions In a surrogate arterial model, burst pressure did not differ between orthogonal and oblique cuts. Given histologically limited lateral thermal spread on PA, angle may be less critical than avoiding vessel tension. ~~Safe vessel dissection was found to depend more on minimizing tension than on dissection angle.~~ These findings may contribute to the safer application of vessel-sealing systems in patients undergoing minimally invasive thoracic surgery.

Keywords: vessel-sealing system, vessel dissection, burst pressure

Introduction

Vessel-sealing systems are utilized surgically to seal blood vessels and achieve hemostasis. This technology has been found to safely assist tissue and vascular dissection in patients undergoing endoscopic surgery [1]. Advanced bipolar devices, such as the LigaSuree™ vessel_-sealing system (Valleylab FT10, Boulder, Colorado), employ a combination of pressure and precisely controlled bipolar energy to denature collagen and elastin within vessel walls, thereby creating a permanent seal. LigaSuree™ has been reported to prevent postoperative chylothorax and bleeding in patients undergoing thoracic surgery [2]. The LigaSuree™ system has been recommended for the safe dissection of small-diameter (diameter (≤ 7 mm) vessels without proximal ligation [3, 4]. Despite the advantages of the LigaSure™ system, it also presents risks, particularly the potential for thermal damage to surrounding tissues [5]. Studies indicate that the extent of lateral thermal damage caused by LigaSure™ is approximately 1.5 mm [6-8], suggesting the importance of preventing thermal damage, especially when operating in the perivascular region.

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Energy devices must be handled with care, particularly when introduced through a small incision. The insertion of energy devices is complicated in patients undergoing uniportal video-assisted thoracoscopic surgery (U-VATS), as the surgical space is more limited using U-VATS than more conventional approaches [9]. To date, however, no studies have evaluated the optimal position and angle for vessel dissection.

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The present study therefore evaluated the effects of lateral thermal damage from the LigaSure™ Xp on the pulmonary artery, measured the burst pressure of a dissected edge cut orthogonally or obliquely to the vessel, and determined the most appropriate position and angle for vascular dissection. Optimizing the position and angle of dissection may enhance the safety of endoscopic surgery.

Materials and Methods

Pulmonary artery dissection and histologic examination

All animals received humane care in compliance with the “Guide for the Care and Use of Laboratory Animals” published by the US National Institutes of Health (NIH Publication No. 85-3, revised 1985). The study is reported in accordance with the

ARRIVE guidelines (https://arriveguidelines.org). The experimental protocol was approved by the Animal Experimental Committee of Fukuoka University (approval No. 2314111). –A dog was sedated with an intramuscular injection of 0.05 mg/kg atropine sulfate, 10 mg/kg ketamine hydrochloride, and 7 mg/kg xylazine and subsequently intubated with an 8-mm endotracheal tube. Mechanical ventilation was maintained using inhalational sevoflurane. Through the thoracotomy incision, the main pulmonary artery was exposed and cut using a LigaSure™ Xp vessel-sealing system (Figure 1). LigaSure Xp was connected with the Valleylab FT10 energy platform. The current and voltage change automatically depending on the condition of the tissue, and the maximum rated voltage is 244 V and the sealing time is approximately 4 seconds. The dog was euthanized using deep anesthesia with an overdose of thiopental sodium. The main pulmonary artery (vascular diameter 7 mm) was resected en bloc, immersed in 10% formaldehyde, embedded in paraffin blocks, and sectioned into 5-mm-thick slices. The sections were stained with hematoxylin and eosin or immunohistochemically with Elastica van Gieson （EVG） stain and examined by light microscopy. Thermal injury was defined as collagen fibers in the vessel wall that exhibited hyalinization and as smooth muscle cells in the tunica media that demonstrated shrinkage and loss of nuclear detail, consistent with coagulative necrosis.

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Burst pressure evaluation

Twenty-four excised swine internal carotid arteries (vascular diameter 5–7 mm), purchased from a meat processing company (TOKYOSHIBAURAZOUKI Co., Ltd., Tokyo, Japan), were cut orthogonally (n = 12, Figure 2A) or obliquely (n = 12, Figure 2B) using a LigaSure~~TM~~ Xp. Dissection at an angle of 90° and 45° to the long axis of the vessel was defined as orthogonal and oblique, respectively. The arteries were individually connected to a handy manometer (Nidec components INC., PG-100B) and fixed with Vicryl sutures (Ethicon, Inc). Each vessel stump was immersed in a container of saline solution and pressure was applied to each using a syringe. The pressure at which bubbles were first observed in the solution was defined as the burst pressure (Figure 3, Video 1). The swine carotid artery was selected as a surrogate medium-sized artery to enable controlled angle testing.

Analysis and Evaluation

Means of continuous variables, such as burst pressure in vessel stumps cut orthogonally and obliquely, were compared by t- tests. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan) software, a modified, graphical user interface of R commander (The R Foundation for Statistical Computing, Vienna, Austria) designed to include statistical functions frequently used in biostatistics.

Results

Microscopic findings

Hematoxylin and eosin staining and Elastica Van Gieson staining

The pulmonary artery was completely sealed and the elastic fibers within the vascular lumen were preserved. However, coagulation of denatured proteins, indicative of lateral thermal damage, was observed along the vessel wall. The length of thermal damage was measured at five points (1.2, 1.2, 1.3, 1.3, and 1.5 mm), and the average value was within 1.3 mm of the sealed section (Figure 4).

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Burst pressure of swine carotid arteries

Average vascular diameter and burst pressure did not differ significantly in swine carotid arteries that underwent orthogonal and oblique resection (6.25 mm vs. 6.17 mm, P=0.813; 829.2 mmHg~~N~~ [range 608–1214 mmHg~~N~~] vs. 949.1 mmHg~~N~~ [range, 593–1306 mmHg~~N~~], P = 0.206) (Figure 5).

Discussion

The present study found that the extent of lateral thermal damage to a canine pulmonary artery when utilizing LigaSure™ XP was approximately 1.3 mm. Additionally, burst pressure did not differ significantly in swine carotid arteries that underwent orthogonal and oblique dissections. Although the insertion angle of the device is limited during thoracoscopic surgery, particularly during U-VATS, oblique vascular resection may be a viable option.

The safety and efficacy of vessel-sealing systems have been extensively documented [10]. Energy sealing without reinforcement was found to enable secure treatment during the resection of pulmonary arteries up to 5 mm in diameter and pulmonary veins up to 7 mm [11]. Although small-diameter vessels patients undergoing thoracic surgery are generally dissected using vessel-sealing systems without ligation, vertical dissection can be challenging in minimally invasive procedures such as U-VATS, where instrument maneuverability is limited. Vertical dissection under these conditions may lead to excessive tension or thermal injury, thereby increasing the risk of inadvertent bleeding. The present study was designed to determine the appropriate vascular dissection technique utilizing vessel-sealing systems, thereby enhancing the safety of vessel dissection in patients undergoing minimally invasive surgery.

Thermal spread is an unavoidable consequence when tissues are dissected using energy devices, such as ultrasonic devices and vessel-sealing systems. Evaluation of the temperature and thermal spread associated with these devices found that thermal spread was greater using LigaSure™ than ultrasonic devices, despite the latter having significantly higher temperatures [12, 13]. Although the use of LigaSure™ for pulmonary vascular dissection necessitates careful consideration of thermal spread, no reports to date have evaluated the extent of thermal damage in the pulmonary arteries of living animals. Examination of the effects of thermal damage on living tissues is important, as thermal spread is dependent on the moisture content within these tissues [13]. Due to ethical considerations, histological evaluation following the dissection of one pulmonary artery in a living dog was performed at five points within the vessel in the present study. The average thermal spread extended approximately 1.3 mm from the dissected site.~~Histological evaluation following the dissection of the pulmonary artery in a living~~

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dog in the present study indicated that thermal spread extended approximately 1.3 mm from the dissected site. The length of the five points did not exceed 2 mm; therefore, it is important that the pulmonary artery is dissected at least 2 mm from the main trunk regardless of the angle of dissection when utilizing LigaSure. Thus, the pulmonary artery should be dissected at least 2 mm from the main trunk when utilizing LigaSure™.

To reduce cutting distance, small-diameter vessels are frequently cut vertically when using vessel-sealing systems. However, the angle of insertion of surgical instruments is constrained by small incisions, with forced insertion for vertical dissection frequently leading to excessive tension on the vessel, thereby increasing the risk of bleeding.

The present study therefore investigated the burst pressure of orthogonal and oblique cutting angles on swine carotid arteries, as conducting pressure testing directly on pulmonary arterial specimens was technically and ethically challenging. Although the carotid artery possesses a thicker and more elastic wall than the pulmonary artery due to its role in high-pressure systemic circulation, previous reports have demonstrated comparable burst pressures after ligation of these two vessels [14]. Considering the results and anatomical similarity of the three-layer structure, the influence of the cutting angle on burst pressure is anticipated to exhibit analogous trends between carotid and pulmonary artery ligations.

Another previous study by Voegele et al. reported that perpendicular vessel seals were mechanically stronger than angled seals [15]. The apparent discrepancy between their results and the present findings may be attributable to differences in vessel size and experimental conditions. In particular, their study evaluated relatively larger vessels, whereas the present study focused on small-diameter vessels comparable to pulmonary artery branches. Vessel diameter, wall thickness, and elastic properties may influence the effect of sealing angle on burst pressure. The burst pressure was significantly higher than the pulmonary artery pressure in both groups, which may be attributed to structural differences in the blood vessels. The angle of artery dissection did not significantly affect burst pressure in the present study, suggesting that, when arteries are sealed uniformly, the pressure per unit area at the vascular stump remains constant. Consequently, the average burst pressure in the oblique and orthogonal resection groups did not differ significantly, suggesting that oblique resection of the pulmonary artery is safe. Maintaining vessel integrity is therefore more critical than the angle of dissection is minimizing excessive tension during the cutting and sealing process.

The current study has several limitations. First, a sample from a single dog was subjected to histological analysis, because of ethical considerations and concerns about animal welfare, as obtaining this sample required dissection of the main pulmonary artery trunk. Second, the pulmonary artery would have been the most appropriate vessel for the burst-pressure test. However, performing such testing on the pulmonary artery was technically and ethically difficult. Consequently, swine carotid arteries were used as a surrogate model. there are structural differences between the pulmonary and carotid arteries. The burst pressure of the pulmonary artery would likely be lower because the carotid artery has a more robust structure. Similar to findings in carotid arteries, the burst pressure in pulmonary arteries would likely be unaffected by the cutting angle. Finally, although it is desirable to resect vessels without applying tension to the vessel walls during energy sealing, tension was not measured in this study.

In conclusion, cutting angle has a negligible effect on burst pressure when small-diameter vessels are dissected using a vessel-sealing system without ligation. More critically, it is essential to minimize excessive tension on the vessel and to take precautions to prevent thermal injury.

Figure Legends

Figure 1

Intraoperative view of the resection of the main pulmonary artery of a dog using the LigaSure~~TM~~ vessel-sealing system.

Figure 2

Picture showing the resection of swine internal carotid arteries using LigaSure~~TM~~ orthogonally (A) and obliquely (B).

Figure 3

Schema of this experiment. (Arrow: swine vessel)

Figure 4

(A) Hematoxylin and eosin staining of a vessel stump. The stump (triangles) was completely closed by coagulation of denatured proteins.

(B) Elastica Van Gieson staining of a vessel stump. Coagulation of denatured proteins, indicative of lateral thermal damage, was observed along the vessel walls from the stump. Scale bars: 200 μm (A and B).

Figure 5

Burst pressure of swine internal carotid arteries resected orthogonally and obliquely. *P = 0.206.

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Declarations

Disclosures Yuichiro Ueda, Jun-ichi Wakahara, So Miyahara, Hiroyasu Nakajima, Fumihiro Shoji, Takeshi Shiraishi, Toshihiko Sato have no conflicts of interest or financial ties to disclose.

Data availability statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

Yuichiro Ueda conceived and designed the study, performed the experiments, analyzed the data, and drafted the manuscript. Jun-ichi Wakahara, So Miyahara, Hiroyasu Nakajima, and Yoshiko Masuda contributed to data acquisition and interpretation. Fumihiro Shoji and Takeshi Shiraishi provided critical revisions for important intellectual content. Toshihiko Sato supervised the study and approved the final version of the manuscript. All authors read and approved the final manuscript.

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Declarations

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