Energy devices for pulmonary artery sealing in video-assisted thoracoscopic surgery (VATS) segmentectomy: literature review and surgical technique

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Objective: To review the application of energy devices for pulmonary vessel sealing and to share our experience using these devices in anatomical segmentectomy.

Background: Due to recent advances in diagnostic technology and the widespread application of lung cancer screening, anatomical segmentectomy has become a popular option for the definitive treatment of early-stage lung cancer. This procedure requires dissection, manipulation and ligation of relatively small pulmonary vessels. The most common reason for emergent conversion of video-assisted thoracoscopic surgery (VATS) anatomical segmentectomy to open thoracotomy is pulmonary vascular injury that happened during the dissection or the manipulation that is required when using endostaplers. Energy sealing devices have a small footprint, which potentially can reduce the risk of vessel injury during surgery.

Methods: In this paper, we systematically searched the literature for animal studies, *Ex vivo* models, and retrospective and prospective studies, reporting on the results of the use of energy devices for pulmonary vessel sealing. We also shared our experience in using these devices in anatomical segmentectomy.

Conclusions: Energy devices for pulmonary vascular sealing of vessels 7 mm or less is both feasible and safe. The learning curve for experienced VATS surgeon is relatively short, and it significantly aids in simplifying minimally invasive segmentectomy.

Keywords: Video-assisted thoracoscopic surgery (VATS); pulmonary artery sealing; energy devices; LigaSure; Harmonic

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Introduction

Anatomical lung resection, including lobectomy and segmentectomy are the preferred surgical treatment for early-stage lung cancer (1). Lobectomy is still considered the standard of care for the surgical treatment of resectable lung cancer, however, sublobar resection for small, non-hilar lesions is gaining popularity and the literature is rapidly evolving. Recent advances in diagnostic technology and the widespread application of low-dose helical computed tomography for lung cancer screening have increased the detection of small lung tumors, and therefore anatomical segmentectomy has become a popular option for patients with both poor lung function and early-stage disease (2). Video-assisted thoracoscopic surgery (VATS) or robotic assisted thoracic surgery (RATS) are the preferred surgical approaches in most patients (3).

During any anatomical lung resection, the ligation of small pulmonary vessels is challenging and pulmonary

vascular injury is the most common reason for emergent conversion to open thoracotomy (4). The technical difficulty and danger are related to vessel dissection, manipulation, stapling, and division that is required when using endostaplers. Energy sealing devices have a smaller footprint than endostaplers and when using these devices, there is less manipulation and dissection required on the pulmonary vasculature. This consequently reduces the risk of iatrogenic vessel injury. In this paper we will review the application of pulmonary vessel sealing using energy devices in anatomical segmentectomy. We present the following article according to the Narrative Review reporting checklist (available at https://jovs.amegroups.com/article/view/10.21037/jovs-21-38/rc).

Methods

We searched PubMed for all studies (2000 to 2021) published in English that report results relating to the use of energy devices for sealing pulmonary vessels in animal studies, *ex vivo* models, retrospective and prospective studies by using the terms: energy devices for VATS or energy devices for pulmonary artery (PA) sealing or energy devices for pulmonary vessels sealing. In our summary table (*Table 1*) we included only animals or prospective studies.

Energy sealing devices in anatomical lung resection

Energy sealing device, such as electrothermal bipolar-activated devices or ultrasonic systems, are widely used in various kinds of surgeries. These instruments are used to achieve adequate hemostasis and safe and easier tissue dissection. The two devices that have been studied in large-scale prospective trials include LigaSure and Harmonic. LigaSure™ (Medtronic, Minneapolis, MN, USA) is an electrothermal device utilizes a combination of pressure and continuous bipolar energy to denatures the collagen and elastin of vessel walls in order to create vessel fusion. Harmonic Ace® (Ethicon Endo-Surgery, Inc., Ohio, USA), uses ultrasonic vibration allowing for the effects of proteins denaturation and coagulation. The two devices are used to seal vessels up to 7 mm in diameter and include a feedback-controlled system that automatically stops energy delivery once the seal cycle is complete.

Recently, LigaSure and Harmonic have been tested for sealing pulmonary vessels (*Table 1*). In an animal model the two devices were found to be safe for sealing a pulmonary vessel smaller than 7 mm (5,9). In human *ex vivo* PA sealing model, the mean bursting pressure of ultrasonic devices was twice as high as bipolar devices (Harmonic 416 mmHg, LiGasure 215 mmHg, EnSeal 134 mmHg) (12). In animal model, the mean tissue temperatures during PA sealing is about the same in ultrasonic and bipolar devices (70–78 ℃) but the instrument blade temperature is much higher in ultrasonic devices (224 *vs.* 83 ℃) (18).

In histological and immunohistochemical analysis of pulmonary vessels divided by LigaSure, it was found that LigaSure sealing result in sealing of the adventitia only, without complete fusion of the layers of the PA walls. It remains unclear whether these findings have a clinical impact (6,7). As a first step for using energy devices in anatomical lung resections, the proximal side of the pulmonary branch were ligated and just after sealed and divided with the devices (10,11). Recently, Okada *et al.* published a prospective study that evaluated the safety of using LigaSure for sealing pulmonary vessels as large as 7 mm during anatomic lung resection, with no additional reinforcing material such as suture ligation or clips. A postoperative hemorrhage occurred in the 128th case, and as a result, they reduced the maximum size of sealing for PAs to 5 mm and completed 200 anatomical resections with no further postoperative hemorrhage (8).

Our group conducted a step-by step approach to demonstrate the efficacy and safety of the Harmonic scalpel for sealing pulmonary vessels of 7 mm or less in diameter. In *ex vivo* models we evaluated the burst pressures of PA branches sealed using different sealing methods. It was found that PAs sealed with ultrasonic energy can sustain higher pressures compared with advanced bipolar energy devices or endostaplers, without seal failures (12,13). In an animal survival study, 10 lobectomies were completed using Harmonic without any bleeding complication at 30 days (14). Then in two sequential phase 1 clinical trials we evaluated the safety of using Harmonic for PA sealing in open and VATS lobectomy (15,16). Recently, we completed a multicenter, international prospective trial in which PA branches of 7 mm or less were sealed and divided with Harmonic. In this study 139 patients underwent lobectomy, and 11 patients segmentectomy, performed by 15 surgeons; 12 of these surgeons had never used Harmonic on pulmonary vessels and learned the technique specifically for the trial. A total of 239 PA branches were divided with Harmonic, 181 with endostaplers, and 4 with endoscopic clips. Intraoperative bleeding occurred in 3 (1.3%) of the PA branches divided with Harmonic and 4 (2.2%) PA branches

Table 1 Summary of published studies on pulmonary vessel sealing using energy devices

Author	Device	Type of study	Main findings	Conclusion
Lacin *et al.* 2007, (5)	LigaSure	Animal study	Twelve sheep underwent lobectomy. All of the vessels were sealed and divided with LigaSure. In 6 cases of right lower lobectomy, following vascular division, ephedrine was injected to increase PAP, and in 6 right upper lobectomy cases, animals were followed and euthanized at 7 days. Dehiscence rate after the increasing of PAP, was 2/6 in PAs and 3/6 in PVs larger than 9 mm. No early or late hemorrhage was seen without ephedrine injection. Overall, no vascular complications were observed in vessels less than 7 mm in diameter	LigaSure can be used for sealing in pulmonary vessels less than 7 mm
Lesser *et al.* 2013, (6)	LigaSure	Prospective study	In 30 cases of open lobectomy, 15 PAs diameter, 3–5 mm, and 15 PAs 6–8 mm, were divided with LigaSure, and the same number and size of PAs were suture ligated. After LigaSure sealing the mean burst pressure of PAs 3–5 and 6–8 mm was 4.3- and 6.4-fold less than after ligation. In histologic examination, fusion of the adventitia only, was demonstrated in all LigaSure sealing cases	The burst pressure of PA after sealing with LigaSure is significantly less compared with suture ligation, and does not result in complete fusion of the artery layers
Yoshiya *et al.* 2018, (7)	LigaSure	Prospective study	LigaSure was used for sealing of 22 PAs and 21 PVs (2–7 mm). Histological findings and thermal damage of the sealed vessels were evaluated. In all divided PAs, a wide area of thermal necrosis and fusion of the adventitia only was documented. Conversely, the wall layers of all divided PVs were completely fused	It remains unclear whether the incomplete fusion and thermal necrosis of the PAs sealed with LigaSure constitute a clinical risk
Okada *et al.* 2019, (8)	LigaSure	Prospective study	In 328 patients, 466 PAs and 402 PVs were sealed. Due to a post-operative PA bleed the study protocol was changed midway and the maximum size of PA sealed with LigaSure was reduce from 7 to 5 mm. Overall postoperative hemorrhage rate was 0.3% (1/328 patients)	Study was changed midway due to a post-operative PA bleed
Nicastri *et al.* 2007, (9)	Harmonic	Animal model	Lobectomies were performed in 9 pigs. Vascular sealing with Harmonic was successful in all arteries 5 mm or less and veins 7 mm or less	Harmonic is a reliable device to divide PAs and PVs s smaller than 5 and 7 mm respectively
Tanaka *et al.* 2009, (10)	Harmonic	Prospective cohort study and animal model	In 20 patients who underwent VATS anatomical lung resection, 43 PAs and 13 PVs 5 mm or less were secured with a proximal single ligation and divided with Harmonic. Vascular sealing was successful in all except two early procedures. There was no postoperative bleeding. In pig model, the bursting pressure of sealed PAs was >75 mmHg	Pulmonary vessels can be safely divided using the Harmonic with proximal single ligation
Toishi *et al.* 2014, (11)	Harmonic, EnSeal, LigaSure	Randomized controlled study	A total of 58 patients underwent lobectomy were randomly allocated to a control group (n=14) and to VSD group (n=44), which comprised three sub-groups: EnSeal (n=17), LigaSure (n=15) and Harmonic (n=12). In the VSD groups, the proximal side of PA stumps (≤7-mm diameter) were ligated and then divided and sealed with respective devices, and in the control group ligated only. The burst pressure of ligation-treated PA stumps was higher than that of VSD-treated stumps. However, the burst pressure for all groups was sufficient to withstand the physiological PA pressure, with no significant differences between the different energy devices. The VSD group demonstrated reduced intraoperative blood loss, surgeon stress, postoperative drainage volume and duration	VSD is simple and safe to use in sealing of PA 7 mm or less when the proximal side is ligated

Table 1 (*continued*)

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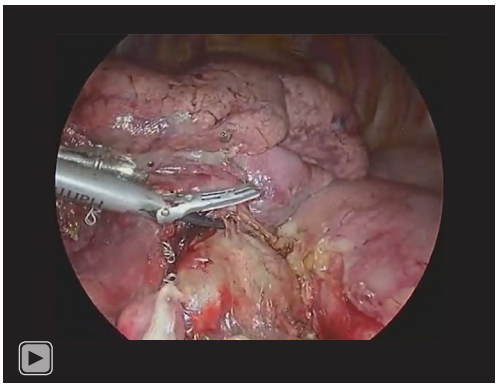
Author	Device	Type of study	Main findings	Conclusion
Liberman *et al.* 2014, (12)	Harmonic, LigaSure, Thunderbeat, EnSeal	Human *ex vivo* PA sealing model	In a human *ex vivo* model, 49 PA branches were sealed using VSD and the burst pressure was evaluated. The mean bursting pressure was as follows: Harmonic 416 mmHg, Thunderbeat 875 mmHg; LigaSure 215 mmHg; EnSeal 134 mmHg	PA sealing using energy was effective and was able to sustain high intraluminal bursting pressures
Liberman *et al.* 2015, (13)	Harmonic	Prospective cohort study, human *ex vivo* model	In specimens from 43 patients, 90 vessels were sealed with Harmonic and 47 were sealed with vascular endostapler. The mean PA branch diameter was 6 mm. The mean burst pressure was 333 mmHg in the Harmonic group and 114 mmHg in the endostapler group. There were no sealing failures in the harmonic group	PA branches sealed using the Harmonic were able to sustain high intraluminal pressures. These pressures were equal to or greater than the stapled vessels
Goudie *et al.* 2016, (14)	Harmonic	Animal survival study	Ten dogs underwent VATS right upper (n=5) and right lower (n=5) lobectomy. Harmonic was used to seal 21 PA branches. No PA branch was divided with an endostapler. One 10-mm PA branch had a partial seal failure immediately at the time of sealing. The device was reapplied on the stump, and the PA branch was successfully sealed. All dogs survived 30 days, with no postoperative bleeding	In an animal survival model, the use of Harmonic for PA branch sealing in VATS lobectomy is safe and effective
Goudie *et al.* 2017, (15)	Harmonic	Prospective phase 1 clinical trial	In 10 patients who underwent open lobectomy, a total of 14 PAs were sealed with Harmonic. The mean vessel diameter was 5 mm (range, 2–7 mm). There was no intra- or postoperative bleeding related to ultrasonic PA sealing	In open lobectomy, PA sealing for vessels 7 mm or less was safely achieved with Harmonic
Goudie *et al.* 2018, (16)	Harmonic	Prospective phase 1 clinical trial	In 20 patients who underwent VATS lobectomy, 31 branches of 7 mm or less were sealed and divided with Harmonic, 24 with endostaplers, 2 with clips, and 1 with sutures. No intraoperative or postoperative bleeding was related to PA branch sealing with Harmonic	In VATS lobectomy, PA branch sealing for vessels 7 mm or less was safely achieved using Harmonic
Liberman *et al.* 2019, (17)	Harmonic	Prospective multicenter multi-center, international phase 2 clinical trial	In 150 patients who underwent VATS lobectomy, 239 PA branches 7 mm or less were sealed with Harmonic, 181 with endostaplers, and 4 with endoscopic clips. Intraoperative bleeding occurred in 3 PA branches divided with Harmonic (1.3%) and 4 PA branches divided with endostaplers (2.2%). There was no postoperative bleeding from divided PA branches with either sealing method	In VATS lobectomy, PA branch sealing with Harmonic, for vessels of 7 mm or less is safe
Goudie *et al.* 2020, (18)	Harmonic, Sonicbeat, Thunderbeat, EnSeal	Animal model	Different types of VSD were used for sealing 37 PA branches were sealed in 4 pigs. The mean tissue temperatures at the site of the sealing measured with a thermal camera were 78, 75, 70 and 82 ℃, and the mean instrument blade temperatures were 224, 195, 83 and 170 ℃ for the Harmonic and Sonicbeat, EnSeal, and Thunderbeat, respectively. The mean diameter of the region with tissue reaching 60 ℃ or more measured with the thermal camera was between 4 and 6 mm for the 4 devices	Instrument blades can reach very high temperatures that may cause tissue damage during and immediately following activation. A 3-mm safety margin between the instrument blades and vital structures is recommended

PA, pulmonary artery; PAP, pulmonary artery pressure; PV, pulmonary veins; VATS, video-assisted thoracoscopic surgery; VSD, vascular sealed devices.

divided with endostaplers. There was no postoperative bleeding from divided PA branches with either sealing method. This study proved that ultrasonic energy is safe for sealing a pulmonary arteries 7 mm or less (17).

Surgical technique for pulmonary vessel sealing using energy devices

LiGasure and Harmonic are widely used in thoracic



Video 1 A video of left superior anatomical segmentectomy. Harmonic Scalpel was used for lymph node dissection and pulmonary artery branch sealing. A pulmonary artery >7 mm and the segmental bronchus were sealed with endostaplers. The segment border was marked with indocyanine green.

surgery. The surgical technique using these two instruments is slightly different (Harmonic allows more sharp dissection while LiGasure requires more blunt dissection technique), but in our experience, the adjustments required to switch from one to the other is simple and needs a short learning curve. In our practice, we use Harmonic routinely in lobectomies and segmentectomies for lymph node and hilar dissection and for the sealing of pulmonary vessels equal to or less than 7 mm. As we mentioned previously, there is also limited data to support the use of advanced bipolar energy for sealing pulmonary vessels, however, the safety data from multiple well designed and sequential safety and efficacy studies for ultrasonic energy use with the Harmonic scalpel is stronger and more mature.

We usually use the harmonic scalpel for sealing of the following branches: posterior ascending arteries of the right upper lobe (RUL) and left upper lobe (LUL), right middle lobe (RML) arteries, superior segmental branch in right lower lobe (RLL) and left lower lobe (LLL). The number of pulmonary arterial branch to the LUL vary from 2 to 7, we usually use the Harmonic for the lingular arteries and for a small posterior segmental branch of the LUL. Harmonic sealing of the PA and segmental veins is ideal for most segmentectomies and in many cases we perform lingulectomy, apicoposterior, and superior segmentectomy using energy sealing only, without using endostaplers for the pulmonary vessels. During segmentectomy we use energy for the entire hilar and lymph node dissection and sealing of any vessel (vein or artery) of 7 mm or less (*Video 1*). Using energy device sealing in segmentectomy reduces the needs for excessive dissection and manipulation in the lung parenchyma near small pulmonary arteries, and avoids the use of the large footprint vascular endostaplers to seal small arteries. These factors have the potential to reduce the risk for bleeding and post-operative air leak. Moreover, it can save 1–3 endostapler cartridges in most segmentectomies and it also significantly reduces surgical time as there is no swapping of devices during the entire operation; dissection, hemostasis, lymph node harvesting and vessel sealing can be done with the same instrument.

There are some key points for successful sealing of pulmonary vessels with energy devices (*Table 2*). The first is to choose the right size vessel and to never use it for vessels larger than 7 mm. We recommend using a sterile ruler on vessels where the surgeon is unsure of the size in order to be sure not to seal vessel which are too large (*Figure 1*). With experience, this becomes unnecessary. When the artery is smaller than 5 mm, it should be sealed with the Min setting with generator set at level "3", and when the vessel is between 5 and 7 mm it should be sealed using the advanced Hemostasis setting. It is very important to perform a complete circumferential dissection before applying the sealing device and to avoid having other tissue (lung, lymph nodes) between the vessel wall and the instrument. Furthermore, a sufficient dissection will ensure that the whole artery is within the instrument blades. Excessive tissue in between the instrument blades or partial artery sealing can compromise the quality of the seal (*Figure 2*).

There are a few technical points which can lead to sealing failure or vessel injury. The vessel needs to lie flat in middle of the instrument blades without any folding (*Figure 3*). When the vessel is in a proper position in between the blades, only one activation should be utilized until the vessel is completely divided. To prevent premature division of the artery, it is very important to avoid tension or torsion for the entire activation. At the end of sealing, the instrument tip can reach temperatures exceeding 200 ℃ (18). To avoid a thermal injury for adjacent vessels, airway and parenchyma, it is critically important to maintain a short distance away from the surrounding tissue during activation, and to cool the instrument on the lung to be removed before using it for subsequent dissection. We strongly recommend leaving a significantly long stump (2–5 mm) (*Figure 4*) to allow easier vascular control in case of sealing failure and to try not to touch the freshly sealed PA stumps with suction or any other instruments following energy division. We do not use clips on the proximal part of the artery branch that

Table 2 Technical tips and recommendations for successful use of energy devices for pulmonary vessel sealing

Use on arteries 7 mm or less
Use sterile ruler if the surgeon is unsure of the vessel size
Use proper instrument settings: MIN for vessels 5 mm and advanced hemostasis for vessels 6–7 mm
Apply on well dissected arteries (skeletonize)
Place the vessel flat in the middle of the instrument blades without folding
Only one activation should be utilized until the vessel is completely divided
Avoid tension or torsion for the entire activation
During activation, try to leave a minimum of 3 mm of distance between instrument blades and vital structures (phrenic nerve, main PA, bronchus, etc.)
During and after the activation, avoid touching surrounding tissues with the instrument blades
Leave a long enough stump for putting clip in case of failure
Following the sealing, before using the instrument for dissection, cool the blades off on the lung to be removed
Avoid touching the freshly sealed vessel stump with suction or any other instruments

MIN, minimal seating; PA, pulmonary artery.

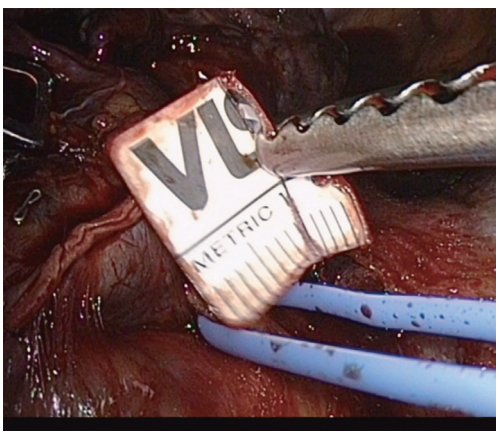


Figure 1 A sterile ruler is used to measure the artery size before applying the sealing device.

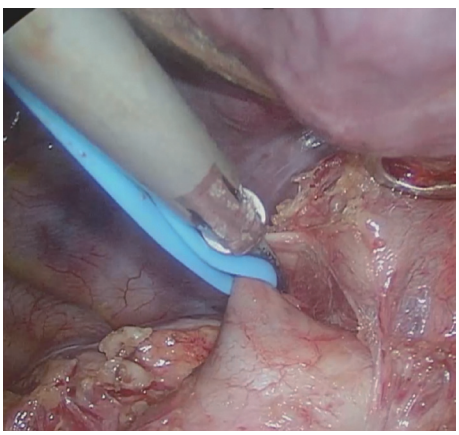


Figure 2 This photo demonstrates incomplete circumferential dissection and excessive tissue in between the instrument blades that can compromise the quality of the seal.

has been sealed. Clips can disturb the proper position of the artery in the blades and may interfere with endostaplers later in the operation. Both factors actually increase the risk of bleeding. We use clips only in the rare circumstance when it is extremely hard to achieve the proper position of the vessel within the instrument blades.

In order to reduce a post-operative air leak, after we divide the segmental vessels and bronchus, we use indocyanine green to mark the segment border and divide it by endostaplers (*Video 1*). We recommend to minimize the use of energy devices for dividing the intersegmental plan as they do not seal the lung parenchyma and associated with air leak.

Conclusions

Using energy devices for sealing of pulmonary vessels 7 mm or less is both feasible and safe. It significantly aids in simplifying minimally invasive segmentectomy. The learning curve for experienced VATS surgeon, is relatively short and safe. This technique can reduce the risk of bleeding during the dissection and manipulation of small branches and can

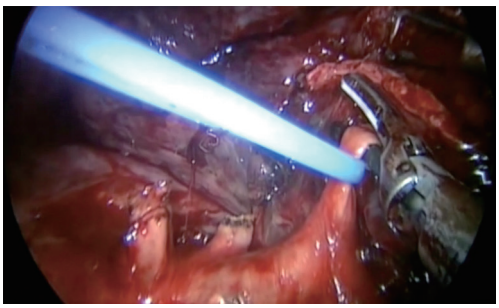


Figure 3 To ensure a good sealing the vessel needs to lie flat in middle of the instrument blades without any folding.

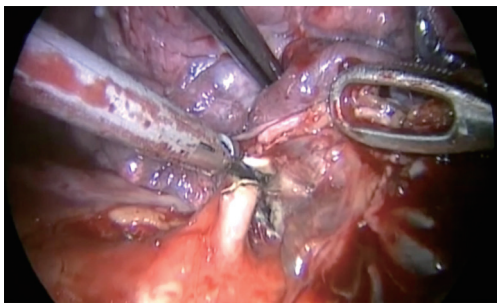


Figure 4 It is important to leave a long stump (2–5 mm) that allow an easier vascular control in case of sealing failure.

reduce the cost and time of surgery.

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