Original Article

Reduction of volume loss after left atrial injury by balloon occlusion—an experimental study

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Background: Advanced-stage lung cancers sometimes require an extensive surgical approach. There is a risk of severe bleeding due to injury to the cardiac atria. Due to the fact that in most cases the surgical planning does not involve the expertise of a heart surgeon or the availability of a heart lung machine, only rapid effective action can avert this life-threatening complication.

Methods: In an experimental study of porcine heart-lung packs, three different methods were used to investigate the most effective way of controlling mass hemorrhage due to left atrial injury. In order to obtain a realistic model, the heart-lung packet was connected to a heart-lung machine after appropriate preparation and perfused with volume support. The damage control to the left atrial injury was either performed by manual compression, surgical clamping or balloon catheter occlusion.

Results: In addition to manual compression and clamping, the use of a balloon catheter inserted into the atrial lesion was found to be the most effective method. The blood loss of 41.88±7.53 mL (*vs.* 105.00±31.74 and 106.00±50.67 mL) proved to be the lowest value.

Conclusions: For extensive resections of lung carcinoma, balloon catheters of different sizes should be kept ready to rapidly control massive blood loss due to injury of the cardiac atria.

Keywords: Mass haemorrhage; left atrial injury; atrial occlusion; balloon occlusion

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Introduction

The so-called T4 lung carcinomas are rare overall, accounting for 7% (1) of all lung carcinomas. The heterogeneous group of T4 lung carcinomas includes all tumours larger than 7 cm and also may present with growth into other organs such as the diaphragm; mediastinum; heart, central blood vessels, trachea, oesophagus, spine, or additional tumour nodules in other lobes of the lung (2). The incidence of T4 tumours invading the left atrium is 3.7% (3) in this group. In most cases, the main tumour mass is in one lobe with the tumour growing along the inferior or superior pulmonary vein directly into the left atrium. The extent of the tumour in the atrium can be very different and ranges from a tumour cone to a broad infiltration of almost the entire atrium to the opposite side. If local resection is possible, the tumour board can recommend resection. Resection is often started without the availability of a heart-lung machine, with the idea of being able to clamp the left atrium at the lesion. If the left atrium is injured during the operation due to the preparation or due to traction, this can

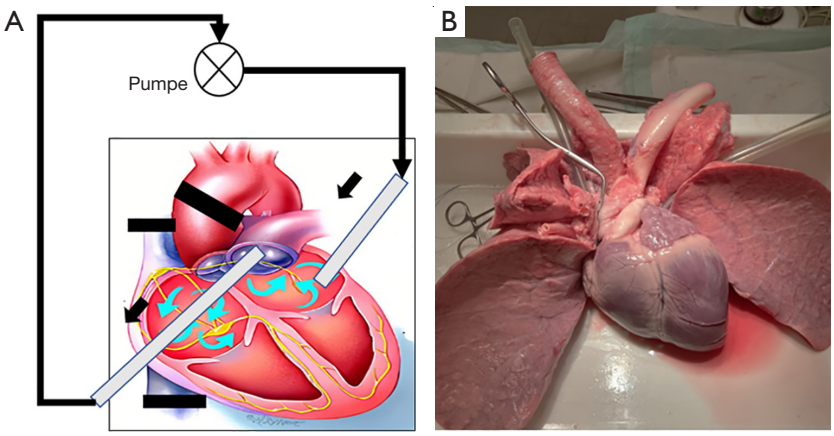

Figure 1 Experimental setting in overview. (A) The graphic shows a schematic overview of the experimental setup connecting the heart-lung machine to the pig's heart, the perfusion circuit with in and outflow cannulas. (B) The original set up with representation of the organ package, the perfusion cannulas of the heart lung machine and clamping of the large thoracic vessels to prevent volume loss. The black arrow defines the inflow and outflow of the perfusion system; the blue arrows define the circulation within the heart.

become a real challenge for the surgeon due to the massive bleeding which occurs immediately. If the lesion is not treated in time, this may lead to the worst-case scenario of death due to blood-loss in the operating room. It should also be borne in mind that not all clinics have a cardiac surgery team and heart-lung machine immediately available in case of an emergency. In the present experimental study, we would like to use an *ex vivo* model with three different treatment strategies after injury to the left atrium and find out which option appears to be the most promising regarding blood loss. We present this article in accordance with the ARRIVE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-247/rc).

Highlight box

Key findings

- Balloon catheters for initial and rapid treatment of cardiac injuries appear to be an optimal surgical tool.
- Therefore, these catheters should always be available for combined cardiopulmonary interventions.

What is known what is new?

- Resections of lung carcinomas can imply severe intraoperative bleeding complications.
- Simple compression and oversuturing are complicated by tight topographic conditions, especially in the presence of severe adhesions through the tumor tissue.
- In the present study, different methods for rapid management of bleeding complications are investigated. Balloon catheter insertion followed by oversewing is shown to be the superior technique.

What is the implication, and what should change now?

- In emergency cases of severe bleeding, surgeons should be prepared having balloon catheters available.

Methods

The entire heart-lung package from freshly slaughtered pigs was removed [European Union (EU) standard: 90 kg]. All specimens were examined for injuries after removal, those with defects were discarded. Procedures were performed according to the International Guidelines for care and use of animals (Guide for the Care and Use of Laboratory Animals 8th Ed, https://nap.nationalacademies.org/). Due to the fact that we had used freshly slaughtered organ packages for the animal experiment, no application was necessary according to our jurisdiction and after consultation with our ethics committee at the Universitätsklinikum Gießen und Marburg (UKGM), Marburg, Germany.

The remains of the pericardium, the pleura, the aorta and the oesophagus were dissected on site. The prepared specimens were packed and immediately transported to our research laboratory. The bypass was already filled with normal saline and prepared in the laboratory. Cannulation was performed venously via the main trunk of the pulmonary artery (cannula from Medtronic two-stage, 18 F, Minneapolis, MN, USA) and arterially via the left atrium (cannula from Medtronic EOPA, 18 F), beforehand a fixation suture was applied (see *Figure 1*). After venting

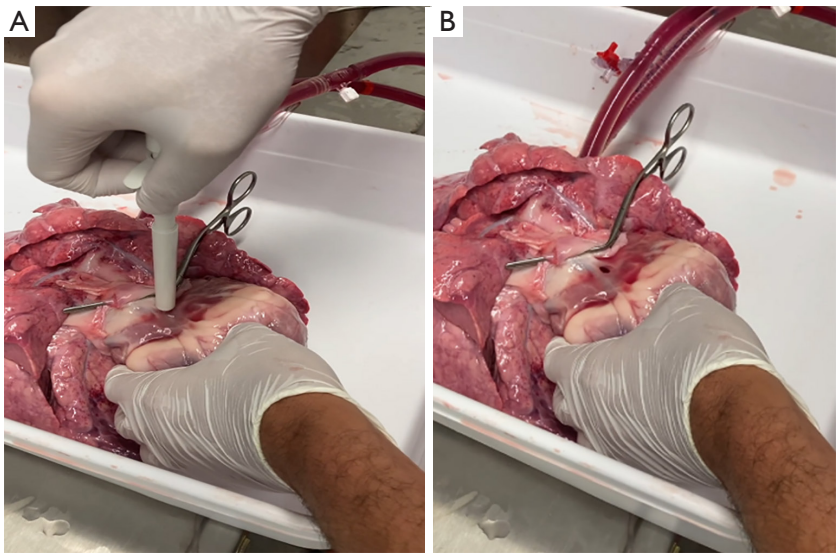

Figure 2 Conduct the experiment by using a punch to place a lesion of definitive size in the left atrium. The cardiopulmonary set is already connected to the perfusion (heart-lung machine, Medtronic, Bio-Console® 560). (A) Setting a lesion in the atrium with a punch; (B) visible lesion in the atrium.

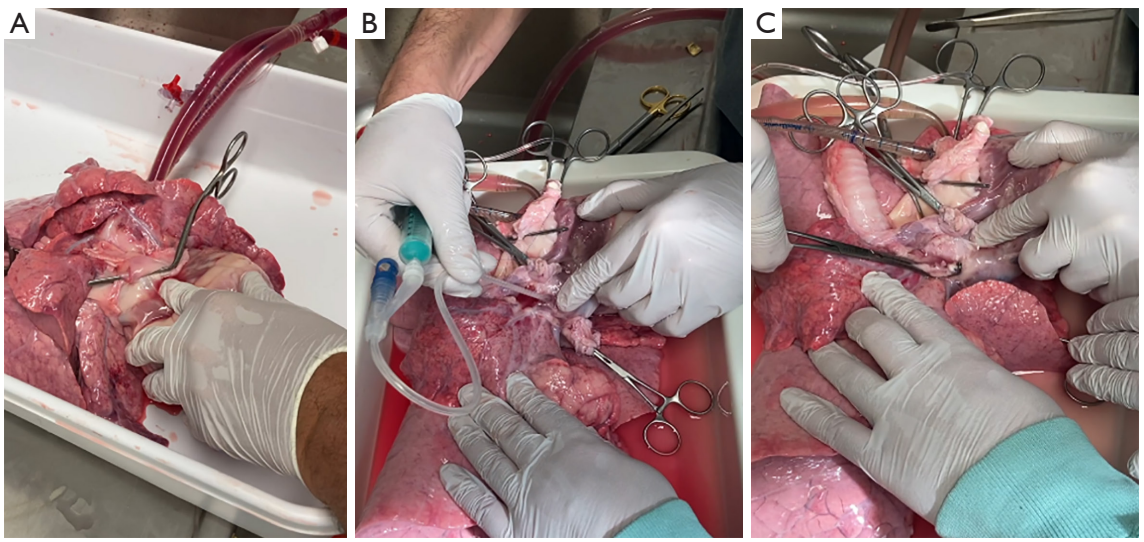

Figure 3 Different ways to close the lesion in the atrium: (A) finger compression, (B) balloon occlusion, (C) clamping.

the bypass, an average flow of 1.76 L/min was established. The pressure in the system was measured using a monitor system. The left atrium was identified and a reproducible 4 mm defect was created in the atrial wall using an aortic punch (QUEST Medical Inc. Rotating Aortic Punch 4.0 mm, Allen, TX, USA). A massive discharge of flushing liquid immediately occurred and was collected in a tray underneath the treatment site (see *Figure 2*).

Three treatment groups (each n=8) with different strategies were defined:

- Group 1: finger compression and suture: the atrial defect is sealed with the finger and then an attempt is made to sew it up with a suture (Prolene 4-0, Ethicon LLC, Sommerville, NJ, USA).
- Group 2: balloon occlusion and suture: a balloon (Coloplast Nelaton™ 12 CH, Humlebaek, Denmark)

Table 1 Comparison of Group 1–3 regarding volume loss

Group	Volume loss (mL)
Group 1	105.00±31.74
Group 2	41.88±7.53
Group 3	106.00±50.67

Data are presented as mean ± standard deviation. Group 1: finger compression and suture: the atrial defect is sealed with the finger and then an attempt is made to sew it up with a suture (Prolene 4-0). Group 2: balloon occlusion and suture: a balloon (Coloplast Nelaton™ 12 CH) is inserted into the atrium, inflated and withdrawn. The defect is then closed with sutures with removal of the deflated balloon before finishing. Group 3: clamping and suture: a curved Satinsky clamp is used to close the defect and then suture it (Prolene 4-0).

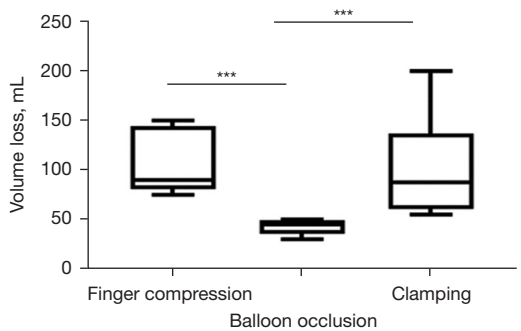

Figure 4 Box blot of the volume loss, comparison of the different closing strategies. Median values are presented according the non-parametric statistical test. ***, P<0.001.

is inserted into the atrium, inflated and withdrawn. The defect is then closed with sutures with removal of the deflated balloon before finishing.

- Group 3: clamping and suture: a curved Satinsky clamp is used to close the defect and then suture it (Prolene 4-0) (see *Figure 3*).

The volume loss (mL) until the definitive closure of the respective lesion was measured. The amount of liquid that escaped from the defect was collected in a tray under the bypass and measured.

The time (measured in seconds/s) until closure of the lesion was measured by stopwatch.

Statistical analysis

Mean volume loss a time until closure in each group was compared by a non-parametric Mann-Whitney *U*-test (significance at P<0.05). The data were evaluated using the statistics program Graph Pad Prism 5 (La Jolla, CA, USA).

Results

The mean initial bypass flow rate was 1.78 L/min (±0.16) with a minimum flow rate of 1.5 and maximum of 2.0 L/min.

With regard to the initial pressure conditions, the mean pressure in the system was 38.38±10.65 mmHg. The minimum pressure was 30 mmHg and at a maximum 61 mmHg was reached.

In Group 1, the mean flow difference before and after treatment of the lesion was 0.49±0.28 L/min, in Group 2 it was 0.40±0.12 L/min and in Group 3 it was 0.57±0.21 L/min.

Comparison of mean flow differences between Groups 1 and 2 showed no significant (n.s.) difference (P=0.68, n.s.). This also applies to the comparison of the mean flow differences between Groups 1 and 3 (P=0.57, n.s.) and also Groups 2 and 3 (P=0.08, n.s.).

In the group with atrial clamping, the mean pressure difference before and after treatment was 10.38±5.60 mmHg. A mean pressure difference of 9.87±5.50 mmHg was measured in the balloon occlusion group. When the defect was occluded with the finger and then sutured, a mean pressure difference of 10.88±7.10 mmHg was registered.

The differences between Groups 1 and 2 were not statistically significantly (P=0.89, n.s.). The same applies to the comparison of the mean pressure difference between Groups 1 and 3 also between Groups 2 and 3 (P=0.812, n.s.).

The mean volume loss in Group 1 was 105.00±31.74 mL with a minimum of 75 mL and a maximum of 150 mL. In Group 2, a mean volume loss of 41.88±7.53 mL was measured. The minimum volume loss in this group was 30 mL, the maximum 50 mL.

The mean volume loss in Group 3 was 106.00±50.67 mL with a minimum volume loss of 55 mL and a maximum of 200 mL (see *Table 1* and *Figure 4*).

If we now compare the mean volume loss of Group 1 with Group 2, we see a highly significant difference (P<0.001). However, there is no significant difference in mean volume loss between Groups 1 and 3 (P=0.46, n.s.). When comparing Group 2 with Group 3 with regard to the mean volume loss, the difference is significant again (P<0.001).

The mean time until closure in Group 1 was 177 s with a minimum of 125 s and a maximum of 220 s.

The mean time until closure in Group 2 was 73 s with a minimum of 58 s and a maximum of 89 s.

Table 2 Measurements of time until closure in group comparison (with mean values)

Group	Closure time (s)
Group 1	177±27.312
Group 2	73±9.76
Group 3	141±28.22

Data are presented as mean ± standard deviation. Group 1: finger compression and suture: the atrial defect is sealed with the finger and then an attempt is made to sew it up with a suture (Prolene 4-0). Group 2: balloon occlusion and suture: a balloon (Coloplast Nelaton™ 12 CH) is inserted into the atrium, inflated and withdrawn. The defect is then closed with sutures with removal of the deflated balloon before finishing. Group 3: clamping and suture: a curved Satinsky clamp is used to close the defect and then suture it (Prolene 4-0).

The mean time until closure in Group 3 was 141 s with a minimum of 108 s and a maximum of 179 s (see *Table 2*).

If we compare the time until closure of the lesion Group 1 with Group 2, we see a highly significant difference (P<0.001). However, there was no significance in Group 1 and Group 3 (P=0.38, n.s.).

When comparing Group 2 with Group 3 with regard to the mean time until closure, the difference is significant again (P<0.001).

Discussion

In the present work we have dealt with iatrogenic intraoperative injury of the left atrium in the context of tumour surgery. Since there is usually no heart-lung machine available for treatment, the blood-loss until closure of the defect can be detrimental to the patient. Using an experimental *ex vivo* model, we dealt with three treatment strategies, focusing on the respective volume loss. A standardised lesion was placed in the atrium in each case for comparability. In the first group, the defect was sealed by finger compression. This should be avoided as it may enlarge the defect through the compression. This procedure was already used by Schirren *et al.* (4,5) and favoured for the treatment of injuries to the pulmonary artery. To be able to close the defect, the finger must be removed during suturing, resulting in more bleeding. This in turn may increase the risk of not being able to close the defect as the situs may become more difficult to control. In this examined group we registered the significantly largest volume loss and longest treatment time.

In the second group, a balloon was inserted into the defect, blocked immediately, and then retracted to occlude the lesion. Stopping volume-loss immediately. This procedure gives the surgeon time to examine the defect and to plan the appropriate closure strategy. Usually, a suture is attached to one side of the defect and an attempt is made to reduce the defect with sutures. After the balloon has been deflated and removed, the remaining required sutures can be applied. Through our investigation, we were able to show that such a treatment leads to the smallest loss of volume and the fastest treatment time. Care should only be taken to not exert excessive tension on the balloon catheter as this may result in the balloon bursting and possible enlargement of the defect. In addition, it is important to ensure that the balloon is of the appropriate size. Balloons that are too large should not be inserted into the defect, as they may occlude the atrium, leading in turn to circulatory failure (6,7). If, as in the third group, an attempt was made to close the defect with a clamp, it can happen that the defect is enlarged or not closed sufficiently (4). This is also due to the anatomical situation, as the atrial walls tend to be stretched out and are difficult to contract. In the worst case, the atrium tears further and further, leaving the surgeon unable to control the situation (8-11). Our investigation confirms this, as volume loss was greatest in this group and also required the longest treatment time.

Comparing all groups, the treatment strategy with balloon occlusion and suture was the one with the lowest loss of volume.

The *ex vivo* model we developed specifically for the study is suitable for investigating the issue. It allows a physiological pressure to build up in the left atrium and thus provides realistic conditions for a bleeding situation. Physiological flow rates were generated through the pump. After the loss of volume began, this was immediately reflected in the drop-in pressure in the left atrium. To compare the treatment strategies, a standardized and reproducible lesion was placed in the left atrium.

However, our *ex vivo* model can only simulate a realistic situation to a limited extent access to the lesion in our model was much better than in a real-life case. After an atrial injury, there is often a large amount of bleeding in an area that is difficult to survey. The overview is completely missing in such situations and locating the site of bleeding is difficult. However, we are convinced that in such a situation, balloon occlusion can better control the bleeding problem compared to other techniques. In addition, it must be considered that the placement of the atrial lesion

was controlled within the framework of the study, i.e., the treatment was carried out immediately after volume-loss occurred. In a real operation, an atrial injury occurs rather suddenly, and until there is a reaction, there is often a considerable loss of blood with the associated consequences.

Our study has shown that in cases of iatrogenic atrial injury, initial balloon occlusion is the most promising option to control bleeding. Since there is a risk of dislocation if the size of the balloon is unsuitable, it is worth considering modifying the shape of the balloon. It would be conceivable to introduce a plate-like "plug" which, after being retracted against the wall of the atrium may seal the defect. This aspect would greatly reduce the risk of dislocation. However, this plug would have to be able to be folded up when closing the suture in order to be easily removed.

In future studies, we want to further investigate various modifications of balloon occlusion in atrial injuries, first using our *ex vivo* model and then using a live animal model in order to further improve the method described in this way.

Conclusions

If an iatrogenic injury to the left atrium is caused during an operation, the least volume is lost when the defect is occluded with a balloon followed by suturing of the defect. Such a blocking balloon should be readily available for any such intervention.

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Footnote

Reporting Checklist: The authors have completed the ARRIVE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-247/rc

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-247/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-247/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Procedures were performed according to the International Guidelines for care and use of animals (Guide for the Care and Use of Laboratory Animals 8th Ed, https://nap.nationalacademies.org/). Due to the fact that we had used freshly slaughtered organ packages for the animal experiment, no application was necessary according to our jurisdiction and after consultation with our ethics committee at the Universitätsklinikum Gießen und Marburg (UKGM), Marburg, Germany.

References

1. Yildizeli B, Dartevelle PG, Fadel E, et al. Results of primary surgery with T4 non-small cell lung cancer during a 25-year period in a single center: the benefit is worth the risk. Ann Thorac Surg 2008;86:1065-75; discussion 1074-5.
2. Lanuti M. T4 disease: exploring changes in the 8th edition of the TNM classification of lung cancer and pushing the limits. Eur J Cardiothorac Surg 2020;57:762.
3. Hamouri S, Alrabadi N, Syaj S, et al. Atrial resection for T4 non-small cell lung cancer with left atrium involvement: a systematic review and meta-analysis of survival. Surg Today 2023;53:279-92.
4. Schirren M, Sponholz S, Oguhzan S, et al. Intraoperative bleeding during thoracic surgery : avoidance strategies and surgical treatment concepts. Chirurg 2015;86:453-8.
5. García A, Millán M, Ordoñez CA, et al. Damage control surgery in lung trauma. Colomb Med (Cali) 2021;52:e4044683.
6. Clancy JF, Carrillo RG, Sotak R, et al. Percutaneous occlusion balloon as a bridge to surgery in a swine

model of superior vena cava perforation. Heart Rhythm 2016;13:2215-20.
7. Cannon J, Morrison J, Lauer C, et al. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for Hemorrhagic Shock. Mil Med 2018;183:55-9.
8. Manning JE, Rasmussen TE, Tisherman SA, et al. Emerging hemorrhage control and resuscitation strategies in trauma: Endovascular to extracorporeal. J Trauma Acute Care Surg 2020;89:S50-8.
9. Boddaert G, Hornez E, De Lesquen H, et al. Resuscitation thoracotomy. J Visc Surg 2017;154 Suppl 1:S35-41.
10. Ball CG, Lee A, Kaminsky M, et al. Technical considerations in the management of penetrating cardiac injury. Can J Surg 2022;65:E580-92.
11. Liu H, Wang Z, Zhang J, et al. Porcine traumatic lung injury model induced by hilum clamping. Injury 2009;40:956-62.

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