

Tamponade Relief by Active Clearance of Chest Tubes

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Purpose. Chest tubes are used in every case of cardiac surgery to evacuate shed blood from around the heart and lungs. Chest tubes can become partially or totally occluded, leading to tamponade. The purpose of this article is to discuss a novel method of maintaining chest tube patency in the early recovery after cardiothoracic surgery.

Description. The PleuraFlow Active Clearance Technology is a system to prevent chest tube clogging that can be used to help routinely maintain chest tube patency at the bedside in the intensive care unit.

Evaluation. A patient exhibited physiologic tamponade that was confirmed by transthoracic echocardiography. The chest tube was successfully reopened by actively clearing the chest tube using Active Clearance Technology, resulting in resolution of the tamponade.

Conclusions. The present study reports the case of a patient with massive postoperative pericardial effusion with tamponade, successfully managed by active clearance chest tube. Further studies will help define the role for this technology in routine cardiac surgery.

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All patients bleed in the early hours after heart surgery [1]. For this reason chest tubes are required to drain shed blood from around the heart until the bleeding stops. It is important that chest tubes remain patent in this critical period of recovery to prevent cardiac tamponade requiring re-exploration. Chest tube clogging, however, is not uncommon and is an issue recognized as a potential problem by nearly all care providers in the intensive care unit (ICU) [2, 3]. Makeshift bedside methods exist to reopen a clogged chest tube, but these techniques have significant practical and safety disadvantages [4–6]. Active Clearance Technology (ACT) is a system to allow routine active clearance of chest tubes at the bedside in the ICU without breaking the sterile field. It has the potential to allow care providers to maintain chest tube patency on an ongoing basis in the ICU or to respond quickly when a chest tube occlusion with tamponade is noticed. We report here the case of a patient who exhibited tamponade within a few hours of arriving in the ICU after cardiac surgery and was successfully managed by active clearance of the chest tube using ACT. Further, we discuss the advantages and disadvantages of ACT in cardiac surgery practice.

Technology and Technique

The PleuraFlow ACT (ClearFlow, Inc, Anaheim, CA) is a system to prevent chest tube clogging that is packaged with two major components: a standard silicone chest tube (Fig 1a), which is equivalent to any other chest tube, and a clearance apparatus (Fig 1b) that is inserted between the chest tube (Fig 1a) and the drainage tubing to the drainage canister (Fig 1c) [7]. The clearance apparatus is made up of a shuttle handle (Fig 2a) on a guide tube (Fig 2b) containing a 0.035-mm polytetrafluoroethylene-coated guidewire that ends in a clearance loop (Fig 2c) toward the chest tube (Fig 2d). The guidewire (Fig 3a) is fitted with several internal magnets (Fig 3b) within the guide tube (Fig 3c). On the outside of the guide tube there is an external magnet (Fig 3d), covered by a shuttle (Fig 3e) that is fitted so it can slide up and down the guide tube. As the shuttle is advanced toward the chest tube (Fig 3f), the clearance wire with the loop is advanced into and out of the chest tube by the coupling action of the internal and external magnets. This allows the user to break up a clot inside the chest tube, freeing it to be pulled toward the suction path to the drainage canister. Frequent use is advised in the early hours of recovery,

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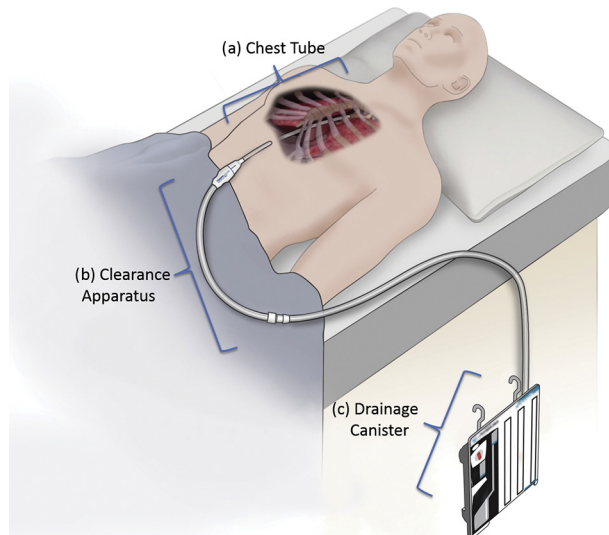


Fig 1. The Active Clearance Technology clearance apparatus (b) is inserted between the chest tube (a) and the tubing to the drainage canister (c).

when the patient is more likely to be bleeding, and less actuation in the ensuing hours once bleeding stops.

Clinical Experience

A 73-year-old man was admitted to our center for myocardial infarction in the context of a severe triple-vessel disease with normal left ventricular function. The patient underwent on-pump triple coronary artery bypass grafting and the operation was uneventful. The ACT system (Fig 3a) was inserted between the anterior mediastinal chest drain (Fig 3b) and the drainage tubing to the canister (Fig 3c) at the end of the operation before closing. The patient was admitted to the ICU in stable hemodynamic conditions and without major bleeding. After approximately 4 hours, the patient experienced

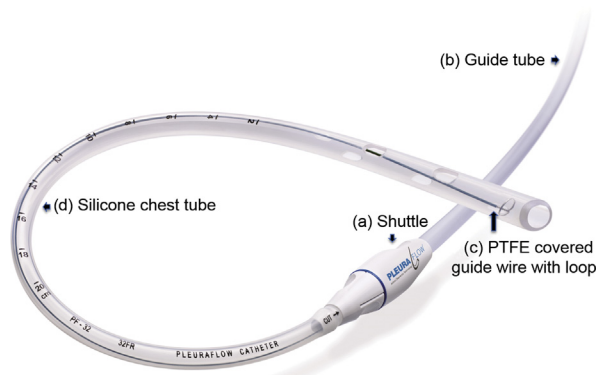


Fig 2. The Active Clearance Technology clearance apparatus consists of a shuttle handle (a), guide tube (b), and polytetrafluoroethylene-coated (PTFE) guidewire and loop for clearance (c). The clearance apparatus is fitted to a chest tube (d).

tachycardia (120 beats/min), initially thought to be secondary to low central venous pressure (6 mm Hg), and evidence of preload hypoperfusion. Two volumes (500 mL each) of normal saline solution were given to elevate his central venous pressure (10 mm Hg), but during the next hour he became increasingly tachycardic (up to 135 beats/min). Despite being of suboptimal quality, the transthoracic echocardiogram subcostal four-chamber view showed a 3.3-cm circumferential pericardial effusion with physiologic signs of tamponade (Fig 4A). Chest tube clogging was immediately suspected. The shuttle guide of the drain was then advanced and retracted along the chest tube several times consecutively, and the clearance loop of the device was finally able to remove clots that had been obstructing the drain. Immediately on removal of these clots with the ACT system, the chest tube drained 200 mL of blood, and a subsequent reduction of the heart rate (120 beats/min) was recorded. A control transthoracic echocardiogram 10 minutes later (see arrows, Fig 4B) demonstrated that the effusion had decreased to 1.55 cm. The next morning, a follow-up transthoracic echocardiogram showed that the effusion had further decreased to 0.99 cm (Fig 4C), and the heart rate had lowered to 110 beats/min. The subsequent postoperative period was uneventful.

In our experience the ACT system has been used in 160 patients and this was the only case of tamponade relief avoiding reoperation; we registered 4 cases (2.5%) of early reexploration for bleeding or tamponade and 1 case of late pericardial effusion. This active clearance chest tube system has been used in approximately 20,000 patients worldwide.

Comment

It is critical that chest tubes remain patent in the early hours after heart operation to prevent pooling of shed blood around the heart that can lead to tamponade. Yet chest tube clogging is quite common [2, 3]. Currently there are no published guidelines or best practices defining what should be done to maintain or reestablish chest tube patency in the ICU. For decades, ICU personnel have stripped and milked chest tubes [4]. These techniques have never been shown to be beneficial, and may even be harmful because of the high negative pressures that may increase bleeding or potentially damage internal tissue [5]. In extreme circumstances, an alternative approach is open suction or the use of a Fogarty balloon catheter to remove the clot [6], but the main problem with these open techniques is that they require breaking of the sterile connection. Given the drawbacks with the age-old methods to clear chest tubes, there is an unmet need for a routine method to maintain or quickly reestablish chest tube patency in the ICU.

The importance of chest tube patency can be illustrated when considering what happens when a chest tube occludes. As a patient bleeds in the postoperative setting, the shed blood is drawn through the eyelets to the lumen of the chest tube by the suction source in the drainage canister (Fig 5a). When blood encounters

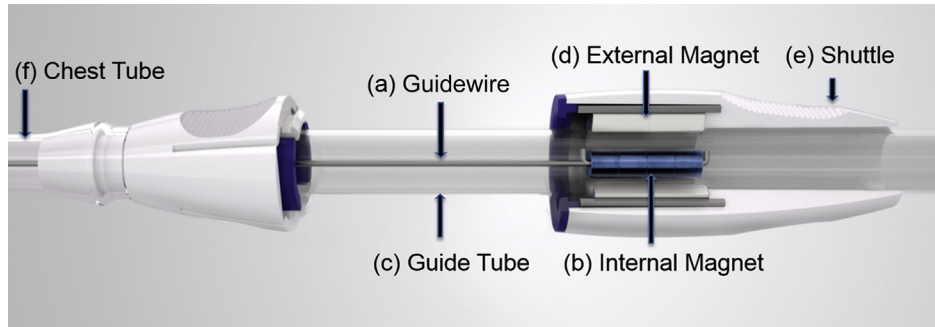


Fig 3. The Active Clearance Technology clearance apparatus consisting of a guidewire (a) fitted to an internal magnet (b) inside a guide tube (c). The internal magnet (b) is coupled to an external magnet (d) through the guide tube (c). The shuttle handle (e) covers the external magnet (d). Actuating the shuttle handle (e) over the guide tube (c) allows advancement of the guidewire with the loop (a) into and out of the chest tube (f) without breaking the sterile environment inside the tube.

the artificial surfaces of the chest tube, a clot can form in the lumen of the chest tube. This not only blocks the drainage through the tube but also prevents the suction of the canister from making it to the mediastinum (Fig 5b). This allows any blood from ongoing bleeding to pool outside of the chest tube in the mediastinum because it is no longer drawn into the chest tube by the suction from the canister (Fig 5c). At first, the blood is still liquid, but with time the blood clots outside the chest tube (Fig 5d). Once the pooling blood clots outside the chest tube in the mediastinum, the chest tube cannot remove it even if it is subsequently reopened (Fig 5e).

Given that no major surgical source of bleeding is frequently found at reexploration, one can speculate that if chest tubes remain patent during the time when the postoperative coagulopathy is corrected and the patient's bleeding stops, many returns to the operating room could be avoided. Our case confirms this hypothesis because after the ACT facilitated drainage of the unclotted pericardial effusion, the postoperative bleeding stopped and no further invasive procedure was required. This case emphasizes the importance of draining the blood before it clots outside the tube.

In this regard, ACT appears promising as a system to routinely maintain chest tube patency or reopen a chest tube at the bedside in the early hours after surgery [8, 9]. Moreover, our case illustrates that even in a case in which a chest tube became clogged between actuations and tamponade ensued, the system is able to restore tube patency and drain pooled blood before it clotted around the heart, thus avoiding the patient from having surgical reexploration.

There are several advantages of ACT over traditional methods to maintain or reestablish chest tube patency. Unlike chest tube stripping and milking (Fig 6a), with ACT the entire lumen of the chest tube is cleared to the end (Fig 6b), and there are no negative pressures generated as the clearance loop is actuated. Compared with open suction or Fogarty balloon catheters, the ACT can be used without the need to break the sterile seal, and as a safety feature, the length of the guidewire with the loop is calibrated so it will not exit the end of the chest tube.

There are also potential disadvantages of ACT. From a practical perspective, ACT requires a commitment by an entire surgical team and nursing staff to derive the maximal benefit of routine chest tube patency. Second, if

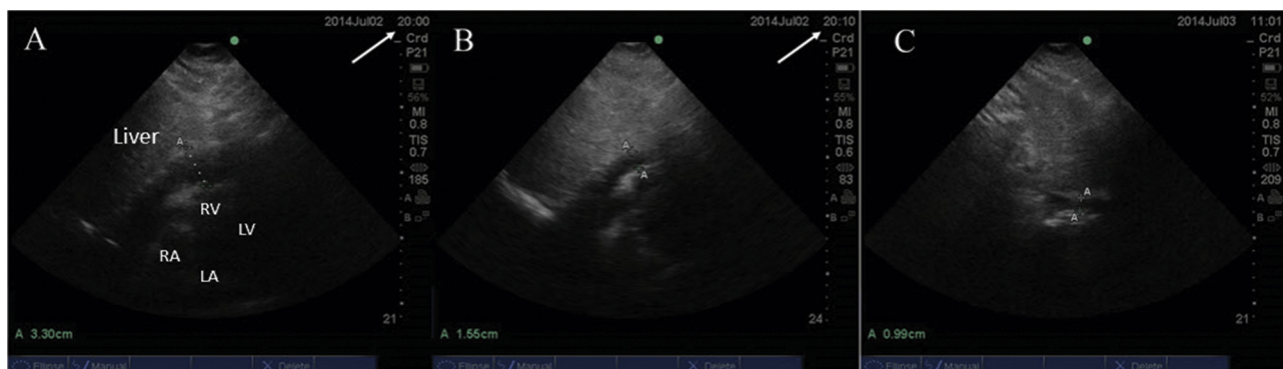


Fig 4. (A) Transthoracic echocardiogram subcostal four-chamber view showing a 3.3-cm circumferential pericardial effusion. (B) A control transthoracic echocardiogram 10 minutes later (see arrows), demonstrating that the effusion had decreased to 1.55 cm, after the active clearance chest tube had drained 200 mL of blood. (C) Follow-up transthoracic echocardiogram 15 hours later, showing that the effusion had further decreased to 0.99 cm. (LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.)

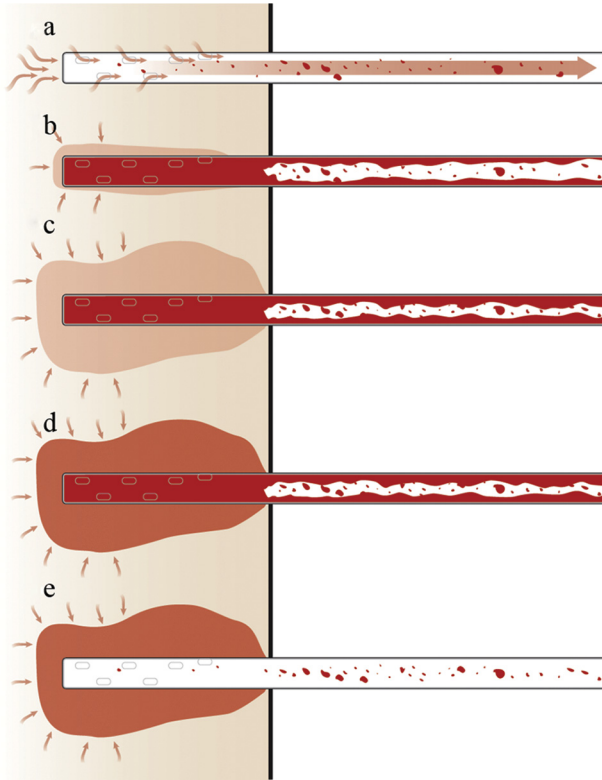
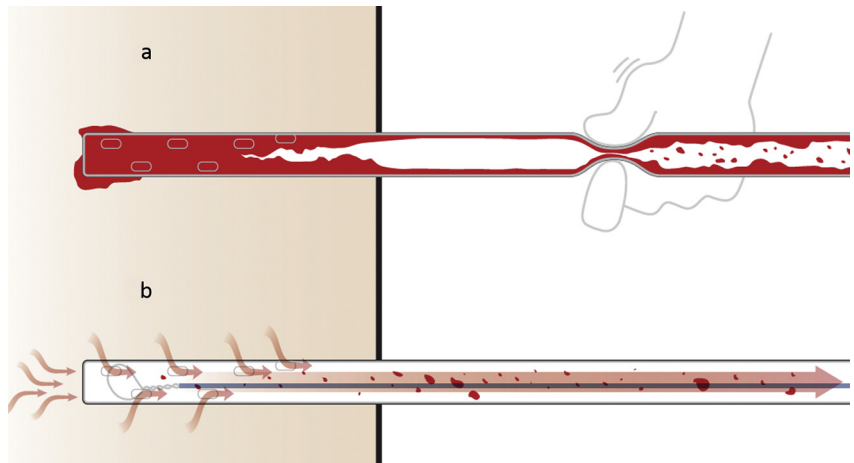


Fig 5. The progression from chest tube occlusion to retained blood. (a) When a chest tube is patent, the suction path is maintained to the drainage canister, drawing blood through the eyelets into the tube. (b) Once a tube lumen begins to occlude, the suction path to the drainage canister is lost, and blood begins to accumulate outside the chest tube. (c, d) Originally this blood is fluid (c), but with time the blood clots (d). (e) Once the blood clots outside the chest tube, reopening of the lumen of the chest tube will be unable to drain the retained blood outside the chest tube.

the chest tube is kinked, the guidewire and loop will not be able to be advanced and retracted. This limits the use to chest tubes that are placed in a relatively straight fashion, such as the anterior mediastinum.

Fig 6. (a) A conventional chest tube that is stripped or milked can only be manipulated to the level of the skin, often leaving the internal portion of the chest tube occluded. (b) With Active Clearance Technology, the entire length of the chest tube can be cleared.



The upfront cost of this device is as follows: 160 cases times \$395 (approximate cost of PleuraFlow if only 1 tube necessary) minus \$30 (approximate cost of 2 standard chest tubes) is \$63,200. From a data set of more than 300,000 cardiac surgery patients, the cost of reexploration and increased associated complications prolonging length of stay is on average \$28,000. However, in our early experience, compared with standard drainage strategies, use of this device seems to be associated with a decreased rate of complications such as tamponade, late pericardial effusions, hemothoraces, and pleural effusions, which all significantly drive up cost.

Study Limitations

This report is intended to illustrate the features of ACT and show how it might be used, but it is not designed to definitively determine the optimal implementation protocols in the ICU, provide definitive evidence of its ability to prevent complications related to retained blood, or provide a rationale for the cost-effectiveness of adding this to a practice. Further studies are needed to establish the best-use protocols, cost to benefit analysis, and to determine whether and how much this might improve outcomes after heart operation.

Conclusions

In conclusion, chest tube patency can be impaired after cardiac operation, and cardiac tamponade requiring surgical reexploration may occur. We report here a case of successful drainage of postoperative pericardial effusion, made possible by the use of a chest tube with ACT.

Disclosures and Freedom of Investigation

Montreal Heart Institute provided all funds for the investigation. The authors had full control of the design of the study, methods used, outcomes, data analysis, and production of the written report.

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Disclaimer

The Society of Thoracic Surgeons, the Southern Thoracic Surgical Association, and *The Annals of Thoracic Surgery* neither endorse nor discourage use of the new technology described in this article.

INVITED COMMENTARY

Vistarini and colleagues [1] describe in the accompanying manuscript an ingenious method of clearing a chest tube of clot and thereby potentially reestablishing tube patency and drainage of the mediastinum. The hope is that this may avoid complications of tamponade, and the need to reexplore for bleeding. The rationale for the latter hope is the common experience in which reexploration for bleeding discloses no bleeding source but the act of removing clot from the mediastinum seems to stop the bleeding—perhaps via the mechanism of removing thrombolytics embracing suture lines.

The device functions through a shuttle collar around the chest tube magnetically linked to a wire within the chest tube, which ends in a loop that moves back and forth, thus loosening up and breaking up occluding clot. No chest tube stripping is required, and because opening the system to suction clot is not required, sterility of the drainage system is maintained.

Two major questions have yet to be answered about the device. The first is whether it is effective. As most clot within mediastinal tubes appears to form within the pericardium (rather than within the tubes), clearing the tube may have little effect on the intrapericardial dynamics. By analogy, suction on a chest tube stuck in a bowl of Jell-O may fill the tube with Jell-O, but removing the tube Jell-O does not impact the Jell-O in the bowl. Of

the 160 patients in this study, 6 had bleeding complications. In only 1 (early tamponade) did the device lead to resolution without the need for operation. In 5 others, reoperation was necessary, 4 for bleeding/tamponade, and 1 for a late effusion.

The second question is whether it is cost effective. The incremental cost of these tubes in the 160 patients was \$63,000. The cost for any reexploration in the institution is \$28,000 (and probably less for uncomplicated reoperation for bleeding). It may be that the cost of saving \$28,000 (or less) is \$63,000.

Both questions will be answered with time as the authors gain increasing experience with this novel device.

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