Drainology: Leveraging research in chest-drain management to enhance recovery after cardiothoracic surgery

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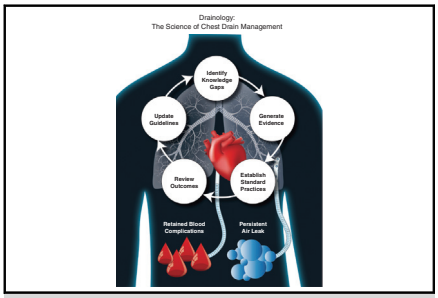
Chest drains are customary in patients recovering after cardiothoracic surgery, although practices vary widely between clinicians, specific procedures, and institutions. In the absence of evidence-based standards, variation may be attributed to experience and may threaten optimal clinical outcomes. Additional research will develop insight and optimize practices in chest drain management, thereby improving perioperative care (Figure 1).

The concept of "drainology" was forwarded as the science of chest drain management and the inaugural symposium titled, "Drainology: Managing Chest Drains in the Postoperative Patient," ensued at the 102nd Annual Meeting of The American Association for Thoracic Surgery (AATS). At that meeting, experts in both cardiac and thoracic surgery gathered to discuss key topics in chest drain management, with the objective of stimulating discussion, inspiration, collaboration, and generation of new evidence-based best practice. The early and enthusiastic response to drainology has stimulated further work[1]; this updated review incorporates the key discussions from the original AATS symposium, subsequent presentations and publications of pertinent research, and a review of recent literature.



Quality improvement in chest tube management through evidence-based standardization.

CENTRAL MESSAGE

Wide variation in the use of chest drains after cardiothoracic surgery can compromise consistency of care and outcomes. The new science of drainology represents an opportunity for quality improvement.

PERSPECTIVE

Current practices for chest drain management are typically based on clinical tradition because of a lack of quality evidence. An iterative process of reviewing new research, building standardized best practices around the findings, identifying knowledge gaps, and conducting new studies designed to bridge them is needed to improve postoperative care and patient outcomes after cardiothoracic surgery.

METHODS

A search of PubMed and Scopus was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines,[2] in order to identify relevant literature published between 2009 and 2024. Primary search terms included chest tube, thoracostomy, chest drainage, chest drain, chest tube clogging, retained blood, anticlogging, retained blood syndrome, active tube clearance, and digital drainage. To capture any product-specific articles, the following search terms were included: PleuraFlow, Thoraguard, Thopaz, Drentech, DigiVent, Atmos, co-axial drain, BLAKE drain, and channel drain. Secondary search terms included thoracic surgeon, cardiac surgeon, heart surgeon, thoracic surgery, cardiac surgery, heart surgery, cardiac, and thoracic.

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Abbreviations and Acronyms

AATS = American Association for Thoracic Surgery
CABG = coronary artery bypass grafting
CPPF = continuous posterior pericardial flushing
ERAS = Enhanced Recovery After Surgery
ESTS = European Society of Thoracic Surgeons
ICU = intensive care unit
LOS = length of stay
POAF = postoperative atrial fibrillation
RCT = randomized controlled trial

Articles were selected for screening if they included 1 or more of the primary search terms and 1 or more of the secondary search terms in the title or abstract. Two reviewers (R.D. and L.P.) screened the abstracts and full texts. Articles were excluded if they were not related to postoperative chest drainage, included only a pediatric population, included veterinary medicine, and/or included the following terms: trauma, emergency department, prehospital, pulmonologist, needle, percutaneous, paramedic, pain, lysis, fibrinolysis, pleural lysis, pleurodesis, talc, spontaneous, or chylothorax. The resulting articles were further divided according to cardiac or thoracic focus.

RESULTS

The initial search yielded 3069 articles, of which 191 were duplicates and 2878 were selected for screening following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses inclusion criteria (Figure 2). In total, 2418 publications were found to be irrelevant, and 460 full-text articles were further assessed for eligibility. An additional 149 were excluded for having the wrong intervention, wrong indication, trauma/emergency setting, pediatric population, or manuscript retracted, and therefore, 311 articles were included in the review (Appendix E2). Of those, 57 of 311 (18.3%) were related to drainage after cardiac surgery and 254 of 311 (81.7%) were related to drainage after thoracic surgery. Of the 57 articles related to cardiac surgery, 21 of 57 (37%) were focused on active tube clearance and 2 of 57 (3.5%) were focused on digital drainage. Of the 254 articles related to thoracic surgery, 36 of 254 (14%) were focused on digital drainage and 1 of 254 (0.4%) was focused on active tube clearance.

Chest Drains: The Guidelines So Far

Cardiac and thoracic surgeons commonly experience distinct postoperative challenges. For example, postoperative hemorrhage and retained blood are risks after cardiac surgery and air leak is rare, whereas air leak is a more common problem after pulmonary resection and hemorrhage is encountered less frequently. Nevertheless, both disciplines share a need for standardization and may be able to benefit through collaboration and sharing of evidence and insights. Evidence-based guidelines for perioperative care after cardiac and pulmonary surgery, the former published by the Enhanced Recovery After Surgery (ERAS) Cardiac Society and the latter by the ERAS Society and the European Society of Thoracic Surgeons (ESTS),[3,4] each contain recommendations specific to chest tube management (Table 1).

Chest tube patency and prevention of retained blood. Postoperative hemorrhage requiring reoperation is a major complication,[5,6] but even in the absence of overt hemorrhage, smaller amounts of retained mediastinal blood are common after cardiac surgery. This blood is associated with proinflammatory processes including hemolysis, oxidation of cell-free hemoglobin, recruitment of immune cells, and generation of reactive oxygen species that affect the myocardium.[7,8] Hence, reliably evacuating shed blood from the thorax and mitigating risks of hemorrhage, hemothorax, tamponade, pericardial and/or pleural effusion, postoperative atrial fibrillation (POAF), organ dysfunction, and infections are central to successful recovery. These complications are also associated with increased ventilation time, intensive care unit (ICU) and hospital length of stay (LOS), 30-day readmissions, mortality, and associated health care costs.[8-12]

Although as many as 2.6% of patients undergo reoperation for hemorrhage after cardiac surgery, it has been estimated that as many as 15 to 20% of patients may, after cardiac surgery, require intervention for 1 or more complications that are known to be associated with retained blood.[9,10] A 2019 multicenter analysis of 30-day readmissions in 2218 cardiac surgery patients in the New England region found that among the 272 patients who were readmitted, pleural or pericardial effusion and dysrhythmia occurred in 19% and 16% of readmitted patients, respectively.[13] Separately, a 2021 systematic review and meta-analysis of 53 studies found that dysrhythmia (4.5-26.7%) and pleural effusion (0.4-22.5%) were among the most frequent underlying causes of readmission in 8,937,457 patients who underwent coronary artery bypass grafting (CABG).[14] The frequency of readmissions related to these complications suggests that prevention of retained blood is a worthwhile target for improvement.

Methods for chest tube clearance. Chest tubes are, of course, designed to reduce retained blood, but an estimated 36% of chest tubes clog after placement, and of those, 86% occlude beneath the skin where they are not visible.[15] A published survey of cardiac surgeons and nurses found that 100% of surgeons had seen chest tube clogging and 87% had observed associated adverse patient outcomes[16]; in fact, surgeons' concerns about clogging were a major reason that they chose larger chest tubes, despite greater pain for patients. The ERAS Cardiac Society guidelines suggest that maintaining chest tube patency may assist with preventing complications associated with retained blood, whereas

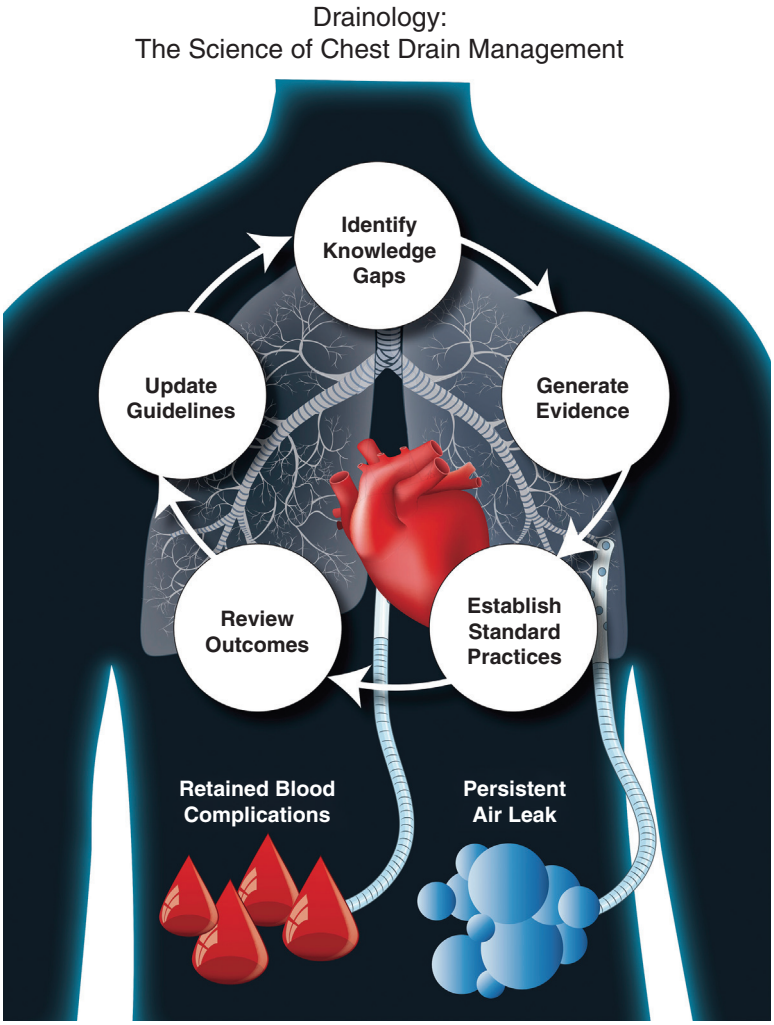

FIGURE 1. Chest drain management in thoracic and cardiac surgery: different challenges but same need for standardization.

both the ERAS Cardiac Society and ERAS Society/ESTS guidelines recommend against common practices such as suctioning or manually "milking" or "stripping" the tubes, as these have no documented benefit, may break the sterile field, and may damage internal tissues (Table 1).[3,4,17]

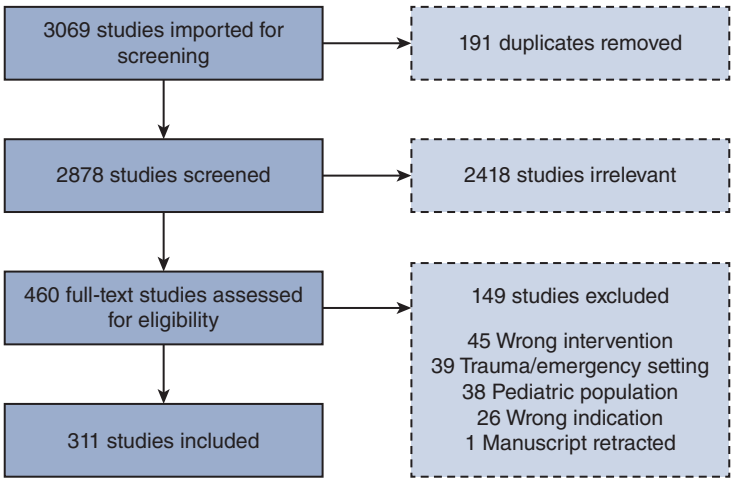

FIGURE 2. PRISMA literature search, disposition of results. *PRISMA*, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

TABLE 1. Evidence-based recommendations for chest tube management

Recommendation	Evidence level/grade
ERAS Cardiac Society recommendations	
Maintenance of chest tube patency to prevent retained blood is recommended	B–nonrandomized studies/ class I
Stripping or breaking the sterile field of chest tubes to remove clots is not recommended	A/class III (no benefit)
ERAS Cardiac Society and ESTS joint recommendations	
Routine external suction of chest drains should be avoided	Low/strong
Digital drains should be used to reduce variability in decision-making	Low/strong
Chest tubes should be removed even if the daily serous effusion is high (up to 450 mL/24 h)	Moderate/strong
A single tube should be used instead of 2 after anatomical lung resection	Moderate/strong

ERAS, Enhanced Recovery After Surgery; *ESTS*, European Society of Thoracic Surgeons.Engelman and colleagues[3] and Batchelor and colleagues.[4]

This may explain in part why one of the largest-growing segments of drainology-related clinical research has been the development of active, automated mechanisms for tube clearance. In our literature search, 37% of papers in the last 15 years referred to this subject. There have been 9 clinical trials, including 1 with randomized design, for the device that uses a magnetic actuation system.[12,18-25,E1]

Seven of the 9 studies showed favorable results, finding an 89% relative reduction in total chest tube occlusion,[12] between 55% and 72% relative reduction in reoperation for hemorrhage and tamponade,[12,20,23] 43% fewer interventions for retained blood symptoms,[25] and as much as a 33% relative reduction in POAF (20% vs 30%, $P = .013$).[18] One study demonstrated a significant reduction in delayed sternal closure,[23] whereas findings from another included fewer procedures to drain pleural effusions, reduced ICU and postoperative LOS, and lower costs of care when active clearance was used.[18]

Two of the 9 clinical studies did not show a benefit. In one, the authors discussed the need for additional training and compliance from the nursing staff to ensure that they were comfortable with chest tube management and used the product per-protocol on a regular basis.[24] This highlights the importance of a systems and protocol-based approach to new techniques and technologies, with training and buy-in from the nursing team, to any active process to prevent chest tube clearance.[E2] It further suggests a need for surgeons to continue to engage their ICU colleagues in any process developed to address this problem.

The other study that did not show a benefit was too small to draw statistical comparisons, with only 50 patients in the active tube clearance intervention arm,[22] and it is therefore not surprising it did not show any benefit. The authors did observe a reduction in POAF.

Most recently, the authors of a systematic review and meta-analysis of 7003 people from 8 of these 9 studies concluded that incidence of reoperation and POAF were more favorable when active tube clearance was used after cardiac surgery.[21] The meta-analysis also showed a reduction in re-exploration for bleeding and a reduction in pleural interventions for effusion.

An important question is whether the incremental cost of active tube clearance is justifiable. Given the reductions in complications, ICU hours, and LOS that are seen in aggregate over the over 7000 patients treated with these devices, one could infer that the reduced overall resource use and health care expenses would justify the costs. This has been explored in one study thus far, in which 337 patients treated with active tube clearance were compared with 300 with standard drainage.[18] The authors found that median costs were reduced by $1831.45 (–$3580.52, $82.38; $P = .04$) and the mean costs reduced by an average of $2696 (–$6027.59, $880.93; $P = .116$). Further studies should include the reduced resource-use end points, such as time on the ventilator, time in the ICU, and LOS alongside actual measured costs. This could go a long way to help teams make real-world decisions with economic data to help inform where the program wants to spend its efforts to reduce costs while at the same time improving outcomes.

Another automated, device-based technology being studied for its ability to safely maintain chest tube patency, known as "air sweep," creates a bolus of sterile air every 5 minutes within the chest tube, ensuring that any fluids stagnating there are swept out and into the drainage reservoir. A small, first-in-human study of this technology in 27 nonemergent cardiac surgery patients failed to show a benefit with only a comparable drainage profile, total output, and readmission rates for effusion compared with 80 conventional controls.[E3] Larger studies will be needed to verify the safety and utility of this interesting potential solution to maintaining chest tube patency.

Digital drain systems for better decision-making. For thoracic surgery, the ERAS Society/ESTS guidelines recommend the use of digital drainage systems to reduce variability in decision-making.[4] Unlike their analog counterparts, digital systems provide a mechanism for continuously and accurately measuring intrapleural pressure over time, the presence and magnitude of air leaks (flow in mL/min), and volume over time of fluid drainage, allowing for both acute assessments and recognition of developing clinical patterns. Some systems are capable of automatically maintaining a predetermined

intrathoracic pressure even when a patient is mobile, potentially enabling air-leak management on an ambulatory or even outpatient basis.[E4,E5] Evidence comparing the effect of digital systems versus analog systems on air leak and chest tube duration after lung resection favors reduction in air-leak duration and time to chest tube removal—on the order of days—when a digital system was used.[E6-E10]

Reduction in interobserver variability in decision-making about chest tube removal may be an important benefit of digital drainage systems, and indeed, it is a matter of some debate whether improvements observed with digital systems are a direct benefit of their variable, regulated pressure capabilities—which allow maintenance of very low and essentially passive, negative-pressure drain settings—or simply that objective data from these systems aid in more consistent treatment decisions. In either case, the outcomes are meaningful and worthy of additional study.

Meanwhile, evidence to support the utility of digital drainage systems after cardiac surgery is scarce but accruing. Three preliminary studies have suggested that digital systems are safe to use in cardiac surgery patients and are associated with reduced air leak, more efficient early drainage of the chest cavity, earlier time to drain removal, and greater satisfaction among clinical staff compared to analog drain systems.[E11-E13] Expanding on these early findings, a presentation at AATS 2023 reported the results of a study comparing outcomes in 1042 propensity-matched patients who underwent CABG managed with either conventional or digital drainage,[E14] but the findings have yet to be vetted through a full peer-review process.

Number of chest tubes and timing of removal after lung surgery. A traditional practice after lobectomy has been to insert more than 1 drain in the pleural space with the logic that more tubes facilitate more complete drainage of air and fluid. However, the belief that more than 1 chest tube is beneficial to all lung surgery patients has been refuted.[4] Although 2 tubes may be appropriate in specific circumstances such as a bilobectomy,[E15] the ERAS Society/ESTS guidelines recommends the use of a single chest tube after lobectomy, noting that multiple tubes show no evidence of advantage, and use of a single tube is associated with less pain, reduced duration of chest drainage, and a smaller volume of fluid drained.

The safety and advantages of earlier chest tube removal after pulmonary resection have also been demonstrated. A study of 100 patients undergoing thoracoscopic lobectomy and segmentectomy found that when chest tubes were removed on postoperative day 0 according to prespecified criteria, 45% of patients were eligible with no reinsertions for pneumothorax while encountering one readmission for delayed pleural effusion.[E16] Similarly, a recent randomized controlled trial suggests early removal, regardless of volume, is associated with shorter duration of drainage and noninferior outcomes.[E17] Compliance with opioid-free analgesic protocols was significantly higher (75% vs 45%, $P = .004$) in patients with early removal, consistent with earlier findings showing that static and dynamic pain scores and ventilatory function improve after chest tube removal.[E18] The ERAS Society/ESTS guidelines suggest that, for thoracic surgery and pulmonary resections, chest tubes should be removed when daily serous effusion is $\leq$450 mL/24 h of nonhematic, nonchylous fluid (Table 1).

In cardiac surgery, it is less clear if rapidly removing chest tubes is equivalent or superior to leaving them in longer. There are 2 studies showing that pericardial and pleural effusions might be greater when the tubes are removed in an expedited fashion.[E19,E20] It is likely that it is more complex than just how long tubes remain in place. Future studies should consider the entire strategy of reducing retained blood as early as possible to prevent any residual blood around the heart and lungs that can be a nidus for inflammatory effusion production in the ensuing days. Thus, looking at studies, alone or combined with specific strategies to reduce retained blood may be a facilitating factor in making early chest tube removal safer and less likely to cause a greater effusion rate later. The entire perioperative care team should be working on a reduction of retained blood strategy in the early hours after surgery and then test if the tubes can come out sooner safely to facilitate earlier ambulation and other benefits associated with this approach.

Questions to Be Addressed in Future Guidelines

Standard chest drain routines after cardiac surgery: One tube, one cut, one day, one way? Aside from patency, the ERAS Cardiac Society guidelines currently lack recommendations to support standardized practices for chest drainage after cardiac surgery. However, development of an effective, evidence-based algorithm that specifies a standard for the materials, sizes, type, and number of drains, posterior pericardiotomy, use of digital drain technology, and duration of therapy could be a powerful means to improve postoperative outcomes. We expect to see new recommendations regarding these questions in future guidelines and expert consensus documents.

For example, a presentation at the 2023 meeting of the European Association for Cardio-Thoracic Surgery titled, "One Tube? One Day?" related evidence supporting use of a single tube and early removal, together with posterior pericardiotomy ("One Cut"), as a proposed standard practice in postoperative care.[E21] The proposal to recommend use of a single tube came from an analysis of 5698 patients undergoing cardiac surgery that found no difference in rates of reoperation for hemorrhage or tamponade, ICU LOS longer than 48 hours, postoperative LOS greater than

9 days, or mortality when 2 chest tubes were placed instead of one.[E22] Another study published in 2019 examined the effect of using an extended drainage protocol (removal on postoperative day 2 with <50 mL drainage in 4 hours, versus on postoperative day 1 with <50 mL drainage per hour, respectively) for patients undergoing cardiac surgery and found that rates of late tamponade were reduced (3.6% vs 8.8%),[E20] but extended drainage had no effect on other complications.

Posterior pericardiotomy drainage is another focus of interest. A systematic review and meta-analysis of 19 randomized controlled trials (RCTs) (3425 patients) by Gozdek and colleagues[E23] found that posterior pericardial drainage was associated with a 58% reduction in POAF ($P < .001$), 90% reduction in the odds of cardiac tamponade (0.42% vs 4.95%; odds ratio, 0.13; 95% confidence interval, 0.07-0.25; $P < .001$), and significant reductions in early and late pericardial effusion, LOS, and odds of mortality or cardiac arrest. More recently, in 2021 Gaudino and colleagues[E24] published the results of the Posterior left pericardiotomy for the prevention of AtriaL fibrillation After Cardiac Surgery (PALACS) RCT. In this adaptive, single-center, single-blind trial in 420 patients undergoing selected cardiac surgical procedures, posterior left pericardiotomy reduced the incidence of POAF by 47% (17% vs 32%, $P = .0007$; adjusted odds ratio, 0.44; 95% confidence interval, 0.27-0.70, $P = .0005$) without an increase in 30-day postoperative complications.[E24] An extension of the trial, which will evaluate the effect of posterior left pericardiotomy on 5-year clinical outcomes, is ongoing (NCT05903222).

Continuous postoperative pericardial flushing (CPPF). Finally, another novel technique that may be worthy of addressing in future guidelines is CPPF.[E25-E28] First described in 2015 in 21 adult patients undergoing surgery for congenital heart disease,[E28] the technique involves continuous, volume-controlled irrigation of the pericardial space after sternal closure with warm saline, which is introduced through an inflow tube placed into the same incision as the pericardial drain. This study, along with a second pilot study in 42 patients undergoing CABG, found that CPPF was associated with a clinically meaningful reduction in postoperative blood loss.[E26] An RCT published in 2020 confirmed that, compared with standard drainage, CPPF improved chest tube patency, reduced blood loss, and reduced pleural effusion in 170 adult patients undergoing surgery for valvular or congenital heart disease,[E27] and a second RCT in 169 patients undergoing CABG found that CPPF therapy reduced median postoperative blood loss by 76% compared with standard drainage ($P = .001$).[E25] Bleeding-related complications such as reoperation for hemorrhage and cardiac tamponade were also reduced, with comparable costs and quality of life.

This strategy to reduce retained blood seems promising, but readers are cautioned that these studies are small. The technology is as-yet untested for potential complications such as chest tube clogging with the fluid being infused, and there are no products with regulatory approval on the market as yet. However, the results to date further validate the hypothesis that strategies to reduce retained blood can be helpful, and suggest that further studies are needed to examine this approach for safety and efficacy at a larger scale.

COMMENTS AND CONCLUSIONS

Currently, the surgical community is far from consensus regarding the optimal type, location, or number of chest tubes and their postoperative duration, much less whether new technologies and devices can offset their own costs or provide overall, net-positive economic value by preventing avoidable adverse outcomes.[E29] However, greater awareness of this expanding field of drainology should encourage practitioners to update their understanding of new evidence, evaluate and question their traditional routines, study the effects of changes and standardization, and scrutinize and share their results for the benefit of others.

An exemplary effort in this regard is the work of Bates and colleagues, published in 2020[E30] and 2021.[E31] As part of a rigorous quality improvement initiative, this group first surveyed chest tube management practices (chest tube removal criteria) and measured outcomes (chest tube duration, chest tube reinsertion, readmission for pleural effusion, and LOS) after congenital cardiac surgery in 1029 patients at 9 centers.[E30] The results of that effort engendered an ongoing collaborative learning project between the 9 centers, in which best practices identified from the center with the most favorable outcomes were used to create practice standards. In the follow-up publication, documented improvements were observed across centers in mean chest tube duration and LOS without increasing complications.[E31] A similar, community-wide commitment to generation of evidence and creation of standard practices based on the results will gradually reduce practice variability and improve quality of care for our patients.

Conflict of Interest Statement

K.W.L. reports consulting relationships with Abiomed, Alexion, Medela, Medtronic, and Renibus Therapeutics. L.P.P. reports consulting relationships with Clearflow, Circulatech, AbbVie, and Marizyme. A.B. reports consulting relationships with Astra Zeneca, BMS, MSD, Ethicon, and Roche. D.T.E. reports that he is on the Device Safety Monitoring Board for Edwards Lifesciences Medical and the advisory boards of Astellas Pharma, Alexion, Terumo, Medela, Arthrex, and Renibus Therapeutics. R.S. reports

relationships with Terumo, Encare, La Jolla, AtriCure, Zimmer Biomet, and JACE Medical. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: chest drain, retained blood, active tube clearance, digital drain, early chest drain removal, posterior pericardiotomy, continuous postoperative pericardial flushing

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Appendix E2. Studies Included After Preferred Reporting Iems for Systematix Review and Meta-Analyses Review

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