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Active Chest Tube Clearance Added to an Enhanced Recovery After Cardiac Surgery (ERAS) Program Improves Outcomes and Reduces Resource Utilization

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Abstract

Objective: We initiated a cardiac enhanced recovery after cardiac surgery (ERAS) program in early 2019, protocolized it and applied it to all patients in 2020, and added the use of active chest tube clearance (ATC) in 2022. Prospective data collection of ATC patients was compared with historical controls to determine the impact of the device on outcomes. **Methods:** The study comprised 1,334 patients with 650 in the control group (group 1) and 684 in the ATC intervention group (group 2). Group 1 (historical control) consisted of 650 patients from January 1, 2020, to October 31, 2020, and January 1, 2021, to October 31, 2021. From October 31, 2021, to December 31, 2021, we introduced ATC use per protocol. Group 2 (ATC) consisted of 684 patients treated consecutively from January 1, 2022, to August 31, 2023, with ATC. The preoperative characteristics and operative procedures between groups were similar. **Results:** Patients in the ATC intervention (group 2) experienced a 41% reduction in the composite of retained blood syndrome (8.2% in group 1 vs 4.8% in group 2, $P = 0.014$). Postoperative atrial fibrillation was 17% reduced for group 2 (178 [33.8%] in group 1 vs 158 [28.1%] in group 2, $P = 0.049$). Group 2 had a 30% reduction in median intensive care unit (ICU) hours (51.6 [30.1 to 76.9] h in group 1 vs 36.3 [20.7 to 687] h in group 2, $P < 0.001$). Twenty-one patients (3.2%) were readmitted to the ICU after initial discharge to the step-down unit in group 1 and only 8 (1.17%) in group 2 ($P = 0.013$). **Conclusions:** The addition of the ATC intervention to an established ERAS program in a high-volume private practice setting decreased complications, improved outcomes, and decreased resource utilization.

Central Message

The addition of the active chest tube clearance intervention to an established enhanced recovery after surgery program in a high-volume private cardiac surgery practice setting further decreased complications and improved outcomes while decreasing resource utilization.

Keywords

cardiac surgery, ERAS, complications, chest tube, pericardium

Introduction

All patients undergoing heart surgery are at risk of complications including postoperative atrial fibrillation (POAF), sanguineous effusions around the heart or lungs, infections, acute kidney injury, and bleeding requiring transfusion or reexploration.[1–4] Once surgical hemostasis has been achieved, early postoperative bleeding results from shed mediastinal blood (SMB) derived at the microvascular level, usually oozing from cut surfaces of the bone, fat, pericardium, cannulation sites, or incisions on the heart.[5] Coagulation abnormalities are common in heart surgery patients and may compound bleeding.[2,6] Evidence points to the role of unevacuated retained blood (RB) in the development of complications such as POAF, effusions around the heart that may cause tamponade or constrictive pericarditis, and pleural effusions. Furthermore, RB may contribute to kidney injury as well as infections and wound-healing issues.[3,7,8] Patients with RB experience more complications leading to increased resource utilization and longer lengths of stay.[9,10] The composite of RB effects is referred to as RB syndrome (RBS), which consists of bloody

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pericardial effusions, tamponade or constrictive pericarditis, and bloody pleural effusions.[7]

Chest tubes are used in every case to evacuate SMB from around the heart and lungs in the early days after cardiac surgery.[11] When the amount of load of evacuated blood, measured as chest tube drainage (CTD) equals the SMB, there is no RB. When the amount of SMB exceeds the amount of CTD, then RB is present.[7] Chest tube clogging, which occurs in more than 36% of patients, can lead to the inadequate or incomplete evacuation of SMB, causing RB.[12] Approximately 86% of chest tube clogging occurs in the segment of the tube within the body where it cannot be identified readily, so it may go unnoticed by the nurses at the bedside.[12]

Active tube clearance (ATC) was developed by surgeons to prevent chest tube clogging. By actuating the device with a magnetic internal clearance apparatus, clots are broken down, preventing chest tube clogging and minimizing the occurrence of RB.[13] Clinical studies have shown that ATC reduces RB, return to the operating room (OR) for bleeding, POAF, and hospital costs.[14–18] Although not all studies have identified the same benefits, when integrated in a meta-analysis, significant reductions in the elements of RBS including take back for bleeding, pleural effusions, and POAF are demonstrated.[19–21] Nearly all clinical studies examining the role of ATC were completed with this same device through the use of a magnetic internal clearance apparatus. There are some newer devices now on the market, and 1 of them uses the movement of air in the tubes to attempt to keep the chest tubes clear.

In the 2019 enhanced recovery after cardiac surgery (ERAS) cardiac guidelines, ATC was attributed a class I, level B-NR rating after thorough examination of the published evidence.[1] Despite the study findings and the ERAS cardiac guidelines Class I recommendation, programs initiating a cardiac ERAS program often do not include ATC in their protocol. The upfront expense to purchase the devices and the need for consistent nurse training and monitoring have been cited as impediments to more widespread use.[22] We initiated a cardiac ERAS program in early 2019, protocolized it in 2020, and added the use of ATC to our developed ERAS program in 2022 (Supplemental Appendix). As is our standard, the addition of the novel technology was accompanied by prospective data collection to be compared with historical controls to determine the merits of the device for our patient population. The findings are presented in this article.

Methods

Group 1 (control) consisted of 650 patients from January 1, 2020, to October 31, 2020, and January 1, 2021, to October 31, 2021. From October 31, 2021, to December 31, 2021, we introduced ATC (Supplemental Video) by providing training for our intensive care unit (ICU) teams for consistent use per protocol (Supplemental Appendix). Group 2 (ATC) consisted of 684 patients treated consecutively from January 1, 2022, to August 31, 2023, with ATC (PleuraFlow, ClearFlow, Inc., Irvine, CA, USA). ATC interventions to reduce chest tube clogging were performed per protocol by the nurses every 15 min for 2 h, then every 30 min for 2 h, then every 1 to 2 h while in the ICU and were documented in the nursing record. Upon transfer of the patient to the step-down unit, actuation was done every 4 h thereafter if the ATC unit was still present.

Structured data elements are routinely prospectively collected and available for retrospective analysis to evaluate baseline, operative, and postoperative data using the standard Society of Thoracic Surgeons Database definitions in our institutional database that we use for continuous quality assurance.[23] RBS is a previously described composite endpoint that encompasses any postoperative reintervention related to 1 or more of the following after heart surgery: reexploration for bleeding with washout of RB, percutaneous pleural interventions (thoracentesis, supplemental chest tube placement, or insertion after the index procedure), surgical pleural interventions (thoracotomy or thoracoscopy for hemothorax after index procedure), pericardial interventions (pericardial window or

Table 1. Preoperative Characteristics.

Variable	All (N = 1,334)	Control (n = 650)	Intervention (n = 684)	P value
Age, years	63.6 ± 12	63.5 ± 12.1	63.6 ± 11.9	0.990
Male	928 (69.6)	436 (67.1)	492 (71.9)	0.057
BMI, kg/m^2	30.5 ± 6.3	30.4 ± 6.4	30.5 ± 6.2	0.670
Diabetes	502 (37.6)	249 (38.3)	253 (37)	0.650
Hypertension	1,152 (86.4)	525 (80.8)	627 (91.7)	<0.001
Preoperative atrial fibrillation	245 (18.4)	123 (18.9)	122 (17.8)	0.620
EF, %	53.3 ± 10.5	52.8 ± 11.1	53.7 ± 9.8	0.160
Preoperative hemoglobin, g/dL	13.7 ± 1.8	13.7 ± 1.9	13.8 ± 1.7	0.510
Preoperative creatinine, mg/dL	1.07 ± 0.49	1.07 ± 0.46	1.06 ± 0.53	0.830
Prior heart surgery	93 (7)	47 (7.2)	46 (6.7)	0.750

Abbreviations: BMI, body mass index; EF, ejection fraction.
Data are reported as mean ± standard deviation or n (%).

Table 2. Intraoperative Variables.

Variable	All (*N* = 1,334)	Control (*n* = 650)	Intervention (*n* = 684)	*P* value
Full conventional sternotomy	1,171 (87.8)	563 (86.6)	608 (88.9)	0.210
Limited minithoracotomy right	130 (9.7)	65 (9.96)	65 (9.48)	*ns*
Partial sternotomy	33 (2.5)	22 (3.4)	11 (1.6)	0.051
Operative procedures				
CABG	702 (52.6)	337 (51.8)	365 (53.4)	0.580
Valve	346 (25.9)	166 (25.5)	180 (26.3)	0.760
CABG and valve	117 (8.77)	66 (10.2)	51 (7.46)	0.099
Aorta	134 (10)	64 (9.85)	70 (10.2)	0.860
Other cardiac	35 (2.62)	17 (2.62)	18 (2.63)	1.000
CPB time, min	130 ± 59.7	131 ± 57.7	129 ± 61.5	0.500
Cross-clamp time, min	95.9 ± 42.5	97.5 ± 44.4	94.6 ± 40.9	0.240
Intraoperative transfusions	187 (14)	103 (15.8)	84 (12.3)	0.069
At least 1 RBC unit	65 (4.9)	34 (5.2)	31 (4.5)	0.610
At least 1 FFP unit	49 (3.7)	32 (4.9)	17 (2.5)	0.020
At least 1 PLT unit	151 (11.3)	87 (13.4)	64 (9.4)	0.024
At least 1 Cryo unit	58 (4.35)	40 (6.15)	18 (2.63)	0.002
Chest tubes placed in OR	1.59 ± 0.58	1.61 ± 0.61	1.58 ± 0.552	0.470
At least 1 bulb drain	175 (13.1)	91 (14)	84 (12.3)	0.370

Abbreviations: CABG, coronary artery bypass surgery; CPB, cardiopulmonary bypass time; Cryo, cryoprecipitate; FFP, fresh frozen plasma; OR, operating room; PLT, platelet; RBC, red blood cells.
Data are reported as mean ± standard deviation or *n* (%).

pericardiocentesis).[7] POAF was defined as an episode of AF requiring treatment, on continuous ambulatory telemetry or electrocardiogram, at any time between the completion of surgery through hospital discharge. Patients who had a documented history of AF or atrial flutter or were in AF or atrial flutter prior to surgery were excluded ($n = 25$).

Chest tubes were placed in the OR just before closing the chest. All patients were implanted with 24 or 28 Fr chest tubes connected to drainage canisters set on −20 cmH_2O suction. Some patients also received a pleural Blake drain set to a bulb suction device. Total CTD included chest tube and bulb drainage. Chest tubes were discontinued when the output was less than 300 mL in the last 24 h. No additional ERAS protocol changes were made during the study period, including transfusion threshold, mobility, and requirements for extubation or discharge.

Results

The study comprised 1,334 patients with 650 in the control group (group 1) and 684 in the ATC intervention group (group 2). The preoperative characteristics between the groups were similar (Table 1). Comparisons of age, gender distribution, body mass index, diabetes, percentage of patients with

Table 3. Postoperative Hospital Outcomes.

Variable	All (*N* = 1,334)	Control (*n* = 650)	Intervention (*n* = 684)	% change	*P* value
Retained blood syndrome	86 (6.4)	53 (8.2)	33 (4.8)	−41.46%	0.014
Reoperation for bleeding, tamponade, or washout	26 (1.9)	15 (2.3)	11 (1.6)	−30.43%	0.430
Postoperative pleural effusion requiring drainage	45 (3.4)	29 (4.5)	16 (2.3)	−48.89%	0.034
Replacement of chest tube	42 (3.1)	26 (4)	16 (2.3)	−42.50%	0.087
Postoperative pneumothorax requiring intervention	21 (1.6)	13 (2)	8 (1.2)	−40.00%	0.270
Postoperative atrial fibrillation	336 (30.9)	178 (33.8)	158 (28.1)	−16.86%	0.049
Highest postoperative creatinine	1.28 ± 0.843	1.26 ± 0.748	1.31 ± 0.924	3.97%	0.240
Dialysis required	22 (1.6)	11 (1.7)	11 (1.6)	−5.88%	1.000
Total ICU stay, h	46.7 (24.0–74.1)	51.6 (30.1–76.9)	36.3 (20.7–68.7)	−29.65%	<0.001
ICU readmission	29 (2.17)	21 (3.23)	8 (1.17)	−63.78%	0.013
Total postoperative length of stay, days	5 (4–7)	6 (5–8)	5 (4–7)	−16.67%	<0.001

Abbreviation: ICU, intensive care unit.
Data are reported as mean ± standard deviation, median (interquartile range), or *n* (%).

Table 4. Postoperative Transfusions and Drainage.

Variable	All (N = 1,334)	Control (n = 650)	Intervention (n = 684)	% change	P value
Any postoperative transfusion	336 (30.9)	178 (33.8)	158 (28.1)	−16.86%	0.049
At least 1 RBC unit	285 (21.4)	146 (22.5)	139 (20.3)	−9.78%	0.350
At least 1 FFP unit	38 (2.8)	26 (4)	12 (1.8)	−55.00%	0.020
At least 1 Cryo unit	48 (3.6)	31 (4.8)	17 (2.5)	−47.92%	0.027
At least 1 PLT unit	65 (4.9)	39 (6)	26 (3.8)	−36.67%	0.074
Drainage at 12 h					
Chest tube drainage, mL	300 (200–415)	300 (200–430)	300 (200–406.3)	0.00%	0.540
Bulb drainage, mL	265 (166.25–390)	295 (195–425)	240 (147.5–370)	−18.64%	0.040
Total chest drainage, mL	330 (240–465)	340 (240–490)	330 (240–450)	−2.94%	0.170
Drainage at 24 h					
Chest tube drainage, mL	560 (390–770)	565 (380–775)	550 (390–766.25)	−2.65%	0.690
Bulb drainage, mL	437.5 (280–625)	490 (300–637.5)	358.5 (277.5–591.3)	−26.84%	0.069
Total chest drainage, mL	610 (440–830)	620 (445–850)	600 (440–816.3)	−3.23%	0.220
Total drainage					
Chest tube drainage, mL	1,046 (620–1,738.5)	1,202.5 (650–1,940)	990 (580–1,562.5)	−17.67%	$<$0.001
Bulb drainage, mL	1,095 (564.4–1,870)	1,312.5 (683.8–2,085)	894 (476–1,557.5)	−31.89%	0.013
Chest drainage, mL	1,242.5 (740–1,973.8)	1,430 (800.5–2,288.3)	1,097.5 (677.5–1,692.5)	−23.25%	$<$0.001
Chest tube dwell, h	72.3 (49.8–97.6)	89.5 (68.7–116.0)	68.7 (47.7–90.1)	−23.24%	$<$0.001
Bulb drain dwell, h	98.5 (69.9–145.1)	117.5 (81.8–162.9)	91.3 (50.5–121.9)	−22.30%	$<$0.001

Abbreviations: Cryo, cryoprecipitate; FFP, fresh frozen plasma; PLT, platelet; RBC, red blood cells.
Data are reported as median (interquartile range) or n (%).

preoperative AF, and ejection fraction showed no significant differences. The ATC group had more patients with hypertension (Table 1). Furthermore, the characteristics of the patient surgeries were statistically similar (Table 2). Incision type, cardiopulmonary bypass, and cross-clamp time were not different. The same surgeons performed all operations during the study periods, and the types of surgeries performed by each surgeon were the same (Supplemental Table). Comparing group 1 versus group 2, the number of chest tubes (1.61 ± 0.61 vs 1.58 ± 0.552, P = 0.470) and the proportion of patients receiving a bulb drain (91 [14%] vs 84 [12.3%], P = 0.370) were also similar.

Patients in the ATC intervention (group 2) experienced a 41% reduction in the composite of RBS (8.2% in group 1 vs 4.8% in group 2, P = 0.014). POAF was 17% reduced for group 2 (178 [33.8%] in group 1 vs 158 [28.1%] in group 2, P = 0.049). Group 2 had a 30% reduction in median ICU hours (51.6 [30.1 to 76.9] h in group 1 vs 36.3 [20.7 to 687] h in group 2, $P <$ 0.001). Twenty-one patients (3.2%) were readmitted to the ICU after initial discharge to the step-down unit in group 1 compared with only 8 (1.17%) in group 2 (P = 0.013; Table 3). Postoperative transfusions and drainage are presented in Table 4.

Discussion

The addition of the ATC intervention to an established ERAS program in a high-volume private practice setting decreased complications and improved outcomes. The findings included a reduced composite of RBS, POAF, CTD, transfusions, ICU time, readmissions to the ICU, and length of stay.

SMB needs to be evacuated or patients are put at risk of developing complications of RB. RBS is a composite of outcomes that derives from the inability to remove blood or bloody fluid from the pericardial or pleural spaces after cardiac surgery.[7] In large case series, it is associated with more complicated postoperative recovery, longer length of stay, higher resource utilization, and increased mortality.[9,10] Included are the need to acutely take a patient back for tamponade or reopen the chest to washout blood clot or bloody fluid. Furthermore, some patients may require thoracentesis of pericardiocentesis in the early days or weeks after surgery.[2,24,25] If chest drains and drainage strategies worked perfectly, these interventions would rarely be needed except in the event of unexpected postoperative surgical bleeding. Given the known high incidence of clogging in more than 1 in 3 standard chest drainage tubes, it stands to reason that methods are needed to optimize SMB evacuation to reduce RBS and expedite recovery.[12]

Adding ATC to our existing ERAS program resulted in a statistically significant 41% reduction in the composite of RBS. The benefit was driven by a reduction in returns to the OR for washouts and reexplorations and decreased need to perform thoracentesis. Our outcomes are consistent with previously published studies that found ATC resulted in decreased take backs as well as fewer postoperative pleural drainage procedures such as placing an additional chest tube or thoracentesis.[14,15,17,18] Pneumothoraces were also reduced likely because of the superior rate of chest tube patency demonstrated with ATC enabling both evacuation of air and liquid.

Although the benefit of a reduction in return to OR is self-evident, the decrease in supplemental drainage procedures also provides a smoother and likely quicker recovery. Over the course of several days, clotted RB can induce an inflammatory response that leads to effusions. The reduction in additional drainage procedures seen with ATC is possibly a result of preventing RB, which decreases inflammation of the pleural and pericardial lining, leading to less fluid production and less effusion. Given that bloody effusions that require postoperative interventions can be recurrent, future studies should extend data collection to include whether recurrent effusions are reduced, even after discharge.

We also observed a statistically significant reduction in POAF. POAF is one of the most common complications of cardiac surgery.[26] Although roughly 20% of patients present for heart surgery with a history of AF, nearly an additional one-third develop new onset of AF in the postoperative period.[27] In the present study, after subtracting patients with preoperative AF, the rate of POAF was reduced by 17%. This reduction is consistent with other studies and was significant in a meta-analysis of patients treated with ATC.[14,17,18,28] Recent evidence suggests that RB undergoing an inflammatory breakdown can trigger POAF in susceptible individuals.[29,30]

In this study, as seen in other published series, there was an overall reduction in bleeding (CTD) and requirement for transfusion. In addition to limiting transfusion exposure, this translated into earlier chest tube removal in the ATC group, aiding in early mobilization. SMB has a high tissue plasminogen activator (tPA) content, and tPA activity is signaled by a high level of D-dimer and fibrin split products resulting from a breakdown of clot in SMB. The tPA in RB comes in contact with recently cut surfaces and could promote microvascular bleeding. Equivalent early bleeding may have resolved more quickly in the ATC group because of less RB.

In today's health care environment, it is important for innovations to have not only a proven clinical benefit but also a favorable health care economic value proposition.[31,32] ATC patients required substantially fewer resources. The ATC group had a 30% reduction in ICU time, with a median of 36.3 h versus a median of 51.6 h in the control group. Even though they left the ICU sooner, they had a significantly reduced ICU bounce-back rate. The significant reduction in transfusions equates to considerable savings in the combined cost of the blood products and staffing to administer them. A 17% reduction in AF also contributed to cost reduction. Patients who develop POAF incur on average $10,000 to $20,000 in additional hospital treatment costs, 12 to 24 h of prolonged ICU time, and an additional 2 to 5 days in the hospital.[26] Finally, the total length of stay was reduced by a day from a median of 6 to a median of 5. The savings and reduced utilization of health care resources justified the cost to use ATC in every case. Many of our patients have Medicare, and thus our hospital receives a fixed payment for the episode of care. Further, Medicare payments to hospitals and physicians will be adjusted down for programs with higher costs and worse outcomes.[33,34] Reducing complications, length of stay, and readmissions is vital to the economic viability of programs and may be achieved through rigorous implementation of novel technology such as ATC. The important benefits are realized when ATC is employed ubiquitously while ensuring proper device activation according to protocol. ATC affects length of stay and readmission by preventing RB complications such as effusions and POAF.

We established a fully integrated ERAS program in 2019. In the past several years, the proliferation of ERAS cardiac programs has led to tremendous advancement for patients recovering from heart surgery.[1,33–36] To date, none of the programs that have published ERAS cardiac results have adopted and tested the inclusion of ATC in their ERAS protocols. To our knowledge, this is the first study of its kind demonstrating the significant incremental benefit of adding ATC to an established ERAS cardiac program.

Our experience with ATC adds to the body of literature challenging a postoperative management strategy that we have accepted for decades. RB is a straightforward problem that requires a direct solution. Science and experience dictate that blood cannot be left in the chest cavity without consequence. Although complications in cardiac surgery are infrequent, they should become rare. The multifaceted benefit of ATC assists in achieving the goal. Like every aspect of perioperative management, current practice in chest drainage should be challenged and refined as evidence leads us to novel approaches to optimize patient outcomes.[11] There remains a need for a better understanding of the risk factors associated with RB complications to further prevent their occurrence.

Limitations

There are several limitations to this study. Data were generated from a nonrandomized, nonanonymized, prospectively collected, observational cardiac surgical database that is used to track our outcomes and submit data to The Society of Thoracic Surgeons supplemented by additional data collection from patient records. The cases during the duration of this study were continuous, which limits the potential for selection bias. The endpoint of RBS is in part derived from the number of interventions performed, rather than by direct imaging. A subjective element is introduced, but given the significantly improved outcomes for the ATC group, it is unlikely that ignoring important RB led to better results.

Conclusions

Our patients and our institution have enjoyed remarkable benefits since the initiation of our cardiac ERAS program in 2019. The program began as a set of loosely associated initiatives and substantially evolved into well-developed and universally applied protocols. Our process serves as a framework for continuous quality improvement. Every addition to the program is scrutinized for clinical outcomes and cost with data collection that will support either continued use or elimination. ATC added significantly to the already positive impact of our cardiac ERAS program, achieving better outcomes for our patients and reduced resource utilization for our institution, generating a positive return on investment.

Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: M.W.G. has served as a consultant for Edwards Lifesciences; has served as a consultant, received research support, and/or served on steering committees for Atrivion, CorMatrix, and Zimmer Biomet; has served as a consultant, received research support, and served as a national principal investigator for AtriCure and CorMatrix; and has served on advisory boards for ClearFlow along with research support from DASI Imaging. C.J. is a paid consultant for Edwards Lifesciences. L.P.P. has served on the scientific advisory boards for Circulatech, Maryzime, Abbvie, and Clearflow.

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Supplemental Material

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