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REVIEW

Effectiveness of Active Chest Tube Clearance Versus Conventional Chest Tube in Reducing Postoperative Complications After Cardiac Surgery: a Systematic Review and Meta-analysis

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Abstract

After heart surgery, the chest tube removes lost mediastinal blood. Clogging of the chest tube may induce inadequate evacuation of fluids surrounding the lungs and heart, leading to deadly consequences. This meta-analysis compared the effectiveness of active chest tube clearance (ATC) with conventional chest tube (CT) in lowering the incidence of retained blood complications after heart surgery. We conducted a systematic search of the available databases to identify cohort studies or clinical trials that met our inclusion criteria. Studies that compared active tube clearance and conventional tube in cardiac surgery were included. The fixed or random-effects model was used to determine the pooled effect estimates upon the heterogeneity of collected data. This review included 7003 people from five cohort studies and three clinical trials. As regard to retained blood, there was no significant difference between chest tube types in matched group (RR = 0.67, 95% CI = [0.44, 1.04], P = 0.08) or unmatched group (RR = 0.64, 95% CI = [0.39, 1.04], P = 0.07). Re-exploration favored ATC in the matched group (RR = 0.64, 95% CI = [0.43, 0.95], P = 0.03). The incidence of postoperative atrial fibrillation was significantly lower in ATC in both matched (RR = 0.73, 95% CI = [0.61, 0.87], P = 0.0005) and unmatched groups (RR = 0.72, 95% CI = [0.61, 0.84], P = 0.0005). This meta-analysis provides evidence on the positive effect of active maintenance of chest tube patency during the first hours of cardiac surgery, which resulted in reducing the incidence of complications.

Keywords Chest tube · Active tube clearance · Cardiac surgery · Re-exploration · Retained blood · Postoperative atrial fibrillation

This article is part of the Topical Collection on *Surgery*.

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Introduction

In the first few hours following heart surgery, almost all patients are suffering from mediastinal bleeding [1]. A significant increase in in-hospital death, duration of hospitalization, and the necessity for postoperative intensive care have been observed in retained blood syndrome after heart surgery [2]. This can give rise to bloody effusion, hemothorax, or even cardiac tamponade. A localized proinflammatory reaction inside the pericardium by the trapped blood may cause postoperative atrial fibrillation (POAF) [3].

To stop blood accumulations around the heart and lungs, almost all patients who undergo heart surgery get chest tubes placed into the pericardial and pleural cavities following the procedure to help with blood drainage. However, chest tubes are vulnerable to obstruction, which can affect drainage

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efficiency and lead to complications such as retained blood syndrome x [2, 4, 5]. The term "retained blood syndrome" refers to the accumulation of blood or a hematoma in the pericardial or pleural spaces that requires evacuation [3]. Chest tube manipulation techniques are thus applied by both nurses and surgeons to eliminate obvious obstructions in the chest tubes [6]. In meta-analyses, chest tube manipulation techniques have been determined to be ineffective or even harmful as the negative pressure on the tissue structures may contribute to the triggering of POAF in susceptible individuals [6, 7].

There have been complications related to conventional chest tubes (CT), and as a result, the ATC (active tube clearance) technology was developed [8, 9]. The use of ATC enables the routine clearance of chest tubes at the patient's bedside in the intensive care unit (ICU) without breaking the sterile internal environment inside the tubes [10]. It may provide ongoing chest tube patency in the ICU or rapid access to a chest tube occlusion with tamponade. ATC was linked to decreased bleeding or bloody effusion interventions with lower POAF incidence [11–13].

Guidelines released by the ERAS (enhanced recovery after surgery) advocated for maintaining the patency of chest tubes while avoiding the breach of the sterile field in cardiac surgery patients and stated that milking of the chest tube was discouraged [14]. According to Vasileios et al. [15], there was no significant difference in postoperative bleeding or degree of pericardial effusion for patients who had undergone valve surgery with the use of ATC when compared to those who used CT. The present study is being conducted to assess whether ATC affects cardiac surgical complications such as retained blood syndrome and the necessity for re-exploration.

Materials and Methods

This systematic review and meta-analysis (SR/Mas) were done in accordance with the *Cochrane Handbook for Systematic Reviews of Interventions* [16]. It is also reported following the PRISMA statement guidelines [17].

Literature Search

We searched PubMed, Scopus, and Web of Science for published articles from inception till June 2021, using the following search terms: "Active tube clearance," "Chest tube," "Cardiac surgery," and "Retained blood."

Eligibility Criteria

We used the Endnote X8 (Thompson Reuter, CA, USA) to import collected records and to eliminate duplicates. Subsequently, we screened titles and abstracts of the included studies as well as the full texts of relevant publications for further evaluation. The references cited in those articles were reviewed. There are at least two authors who worked independently to select studies, extract the data, and analyze them. We included studies that matched the following criteria: (I) population, adult or older adults who underwent any type of cardiovascular operations; (II) intervention, active tube clearance; (III) comparator, conventional chest tube; (IV) outcomes, retained blood, re-exploration, postoperative atrial fibrillation, pneumothorax, pneumonia, stroke, mortality, urinary tract infection (UTI), ICU time, hospital stay, total ventilation time, pneumonia, plural interventions, pericardial interventions, cardiac tamponade, pleural effusion, sternal infection and cardiac arrest; and (V) study design, clinical trials and cohort studies. Only articles available in English were included. Our criteria for exclusion were as follows: (1) editorials, abstracts, thesis, letters, books, and chapters, (2) studies with unreliable data for extraction and analysis, and (3) study data gained from an abstract only.

Data Extraction

According to the eligible research, the following information was gleaned: (1) summary and overview of the included studies: authors, publication date, geographic area, sample size, study arms, and research design; (2) baseline features of included study participants: age, gender weight, diabetes, hypertension, type of cardiac operation, type of ATC system, preoperative arrhythmia and prior percutaneous cardiac surgery; and 3) outcomes: including retained blood, re-exploration, postoperative atrial fibrillation, pneumothorax, pneumonia, stroke, mortality, UTI, ICU time, hospital stay, and total ventilation time.

Risk of Bias Assessment

The risk of bias tool developed by the Cochrane Collaboration was used to appraise the methodological quality of the studies included in this review [18]. Selection, performance, detection, attrition bias, reporting, and other possible biases are assessed by this tool. Third-party reviewers assigned each bias domain a value of "low," "high," or "unclear." Cohort studies' quality was assessed using the Modified Newcastle–Ottawa scale [19]. We could not assess the publication bias using Egger's test for funnel plot asymmetry, because the number of included studies was less than ten.

Statistical Analysis

The data were statistically analyzed with Review Manager (version 5.4). For continuous outcomes, data were presented as mean difference (MD) and 95% confidence interval (*CI*). While for dichotomous outcomes, data were presented as relative risk (RR) and 95% *CI*. The chi-square and *I*-square tests were used to determine heterogeneity. When the chi-square *P*-value was less than 0.1 and the *I*-value was greater than 50%, then heterogeneity was taken into consideration. The fixed-effects model was applied to conduct the analysis. Once the pooled data were heterogeneous, we used a random-effects model then we attempted to fix the heterogeneity by sensitivity analysis.

Results

Screening Process and Study Selection

The databases' electronic search and references lists review identified 113 articles. After duplicate removal, 97 articles were assessed through screening. Of those, 17 articles were included after the primary screening. The full texts of these articles underwent secondary screening in which only eight articles [11–13, 20–24] were found to have completely met the inclusion criteria. The process of identifying the included articles is demonstrated in Fig. 1.

Description of Studies

Table 1 provides an overview of the studies that were included. Three [20–22] of the included studies are clinical trials, while the other five studies are cohort studies [11–13, 23, 24]. A total of 7003 patients were investigated, including 5083 patients who underwent conventional chest tube (CT) after cardiac surgery and 1920 patients who underwent active chest tube clearance (ATC). The mean ages of patients ranged between 65.1 and 68.9 years. All included studies used ATC or CT for pleural cavity drainage. The studies included patients with urgent and elective cardiac surgeries like coronary artery bypass grafting (CABG), valve replacement, and thoracic aortic surgery (Table 2).

Fig. 1 The study flow diagram

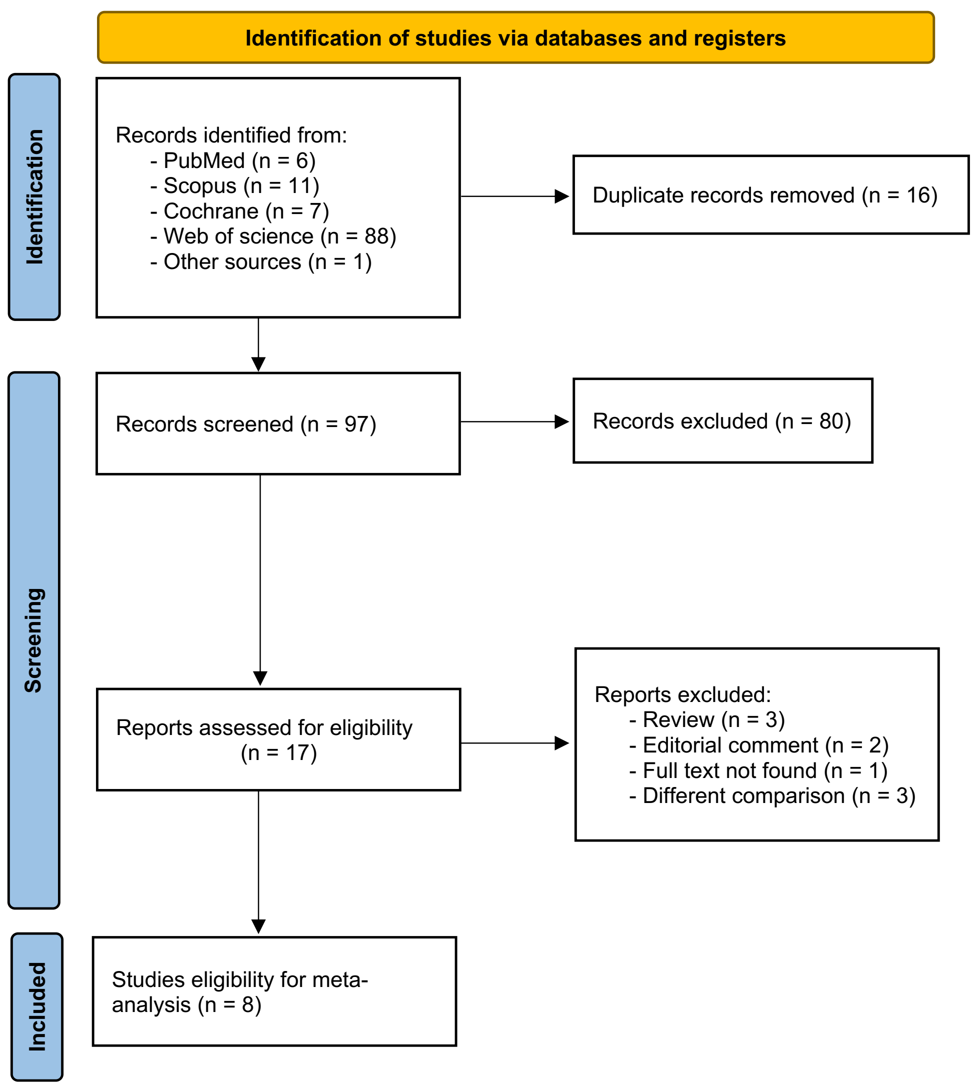

Table 1 Shows the baseline and summary of the studies included in the meta-analysis

Study ID	Site	Study design	Follow-up period	Type of cardiac surgery	Study arms	No. of patients	Age	Gender (male) *n* (%)	Weight (kg)	BMI (kg/m2)	NYHA *n* (%)	Diabetes *n* (%)	Hypertension *n* (%)
Baribeau et al. 2019	England	Cohort	4 weeks	CABG + VALVE	CT	302	65.1 ± 12.6	205 (68%)	88 ± 20		162 (54%) type I _ 140 (46%) type II or III or IV	118 (39%)	243 (80%)
					ATC	337	67 ± 10.2	236 (70%)	90 ± 21		167 (50%) type I _ 170 (50%) type II or III or IV	156 (46%)	272 (81%)
Grieshaber et al. 2018	Germany	RCT	-	Cardiac surgical with median full or partial sternotomy	CT	359	66 ± 11	267 (74.4%)	-	28 ± 5.3	-	-	-
					ATC	222	68 ± 9	175 (78.8%)	-	28 ± 5.3	-	-	-
Sirch et al. 2016	Germany	Cohort	-	CABG, valve,CABG þ valve, and other	CT	1894	68.7 + 10.7	197 (77%)	-		NYHA Class I 139 (8%)	-	241 (94%)
					ATC	256	68.1 + 10.9	1327 (72%)	-		NYHA Class I 17 (7%)	-	1680 (91%)
St-Onge et al. 2017	Canada	Cohort	4 weeks	CABG or valve replacement or both	CT	158	65.7 ± 12.1	100 (63%)	-	28.7 ± 6.0	NYHA Class II 469 (25%)	64 (41%)	120 (85%)
					ATC	142	66.1 ± 11.0	110 (78%)	-	29.8 ± 5.1	NYHA Class II 38 (15%)	48 (34%)	132 (84%)
St-Onge et al. 2021	Canada	RCT	4 weeks	CABG and/or valvar heart surgery	CT	263	65.9 ± 10.8	206 (78%)	-	29.4 ± 5.6	NYHA Class III 1093 (59%)	97 (37%)	208 (81%)
					ATC	257	66.6 ± 8.6	203 (79%)	-	30.0 ± 5.4	NYHA Class III 179 (70%)	113 (44%)	213 (81%)
Vasileios et al. 2020	Switzerland	Cohort	-	CABG, valve surgery, thoracic aortic surgery	CT	1980	68.6 ± 11.6	1541 (78%)	79.67 ± 14.09	26.73 ± 3.85	-	423 (21%)	366 (76%)
					ATC	481	65.7 ± 10.5	364 (76%)	80.33 ± 14.13	26.067 ± 4.46	-	93 (19%)	1433 (72%)
Malgerud et al. 2020	Sweden	RCT	4 weeks	Aortic valve surgery	CT	50	60 ± 12	43 (86%)	87 ± 15	27 ± 5	-	1 (2%)	22 (44%)
					ATC	50	62 ± 13	40 (80%)	84 ± 17	27 ± 5	-	6 (12%)	22 (44%)
Maltais et al. 2016	USA	Cohort	-	Left ventricular assist device (LVAD) implantation	CT	77	53 ± 10	63 (82%)	91 ± 19	-	NYHA class IV 76 (99%)	31 (40%)	51 (66%)
					ATC	175	53 ± 13	139 (79%)	91 ± 21	-	NYHA class IV 175 (100%)	67 (38%)	112 (64%)

NYHA, New York Heart Association; *CABG*, coronary artery bypass graft; *RCT*, randomized controlled trial; *CT*, conventional tube; *ATC*, active tube clearance; *BMI*, body mass index; data reported in mean ± SD

Quality Assessment

According to the Cochrane tool [18], one RCT was free from any source of bias [21]. In terms of detection bias, Malgerud et al. [20] have a high risk of bias, whereas Grieshaber et al. [22] have a high risk of bias in terms of selection bias (Supplementary Figs. 7, 8). According to the Modified Newcastle–Ottawa scale [19], the most common methodological weakness in all cohort studies was the way of outcome assessment. However, the risk of bias related to participant selection, comparability of cohorts based on the design or analysis, and the reporting of outcomes was generally considered low (Supplementary: Table 3).

Outcomes Measure

Retained Blood (RB)

The RB data were reported in six studies [11, 13, 21–24] (Fig. 2). Statistically, there was no difference between the two chest tubes in the pooled RR, regardless of whether the patients were matched (RR = 0.67, 95% CI = [0.44, 1.04], P = 0.08) or not (RR = 0.64, 95% CI = [0.39, 1.04], P = 0.07), with significant heterogeneity in matched $I^2 = 85\%$ (P = 0.0002) and unmatched $I^2 = 92\%$ ($P < 0.00001$). The detected heterogeneity was resolved by leaving Vasileios et al. [24] out, which significantly affects the results in matched (RR = 0.57, 95% CI = [0.45, 0.72], $P < 0.00001$) and unmatched (RR = 0.53, 95% CI = [0.43, 0.66], $P < 0.00001$).

Re-exploration

The re-exploration data were available in all included studies [11–13, 20–24] (Fig. 3). Re-exploration was found to be significantly improved when the results were pooled favoring the ATC group in matched group (RR = 0.64, 95% CI = [0.43, 0.95], P = 0.03) and the results were homogenous in matched $I^2 = 26\%$ (P = 0.24) (Fig. 3A). Also, it was found to be significantly improved in unmatched group (RR = 0.58, 95% CI = [0.35, 0.96], P = 0.03) and the results were heterogenous $I^2 = 56\%$ (P = 0.04) (Fig. 3B). The detected heterogeneity was resolved by leaving Maltais et al. [11] out, and the results became insignificant (RR = 0.69, 95% CI = [0.41, 1.16], P = 0.17, $I^2 = 34\%$ (P = 0.19)).

Postoperative Atrial Fibrillation (POAF)

The data of POAF were reported in six studies [11–13, 20, 21, 23] (Fig. 4). As compared to the CT group, the pooled RR of POAF occurrence was lesser in ATC group in both matched (RR = 0.73, 95% CI = [0.61, 0.87], P = 0.0005) and unmatched groups (RR = 0.74, 95% CI = [0.63, 0.85], $P < 0.0001$). The results were homogenous in matched $I^2 = 35\%$ (P = 0.20) and unmatched groups $I^2 = 0\%$ (P = 0.51).

Pneumothorax

Three studies [13, 21, 24] reported the incidence of pneumothorax in patients undergoing cardiac surgery (Fig. 5). No difference was seen in the RR between the two types of chest tubes when they were pooled together in both matched (RR = 0.88, 95% CI = [0.54, 1.43], P = 0.60) and unmatched groups (RR = 1, 95% CI = [0.7, 1.43], P = 0.99). The results were homogenous in matched $I^2 = 0\%$ (P = 0.58) and unmatched groups $I^2 = 0\%$ (P = 0.79).

Stroke

Four studies [11–13, 23] reported the data of stroke incidence after cardiac surgery (Fig. 6). The pooled estimates revealed that there was no significant disparity between CT and ATC in stroke in both matched and unmatched groups (RR = 1.14, 95% CI [0.42, 3.13], P = 0.80) and (RR = 1.74, 95% CI [0.62, 4.87], P = 0.29), respectively. The pooled estimates were homogenous in matched (P = 0.88, $I^2 = 0\%$) and unmatched (P = 0.97, $I^2 = 0\%$) groups.

Mortality

Data regarding the mortality were reported by all studies except Vasileios et al. [24] and Malgerud et al. [20] 1756 patients for ATC and 1645 patients for CT (Supplementary Fig. 9). The pooled results showed a non-significant increase in mortality rate in matched group (RR = 1.44, 95% CI [0.89, 2.33], P = 0.13) and unmatched group (RR = 1.03, 95% CI [0.62, 1.71], P = 0.91). The heterogeneity was (P = 0.06, $I^2 = 59\%$) and (P = 0.92, $I^2 = 0\%$) in matched and unmatched groups, respectively.

ICU Time (Hours)

The mean hours of patients' ICU stay time was reported in four studies [11, 12, 21, 23] (Supplementary Fig. 10). The pooled (unmatched) results showed a non-significant decrease in ICU stay time, with a MD of − 6.96 (95% CI, − 17.57 to 3.64; P = 0.2). The heterogeneity was statistically significant ($P < 0.0001$); $I^2 = 86\%$. By omitting Baribeau et al. [23], we were able to get rid of this heterogeneity without any significant effect on the results (MD = − 1.91, 95% CI = [− 9.13, 5.31], P = 0.6) with heterogeneity $I^2 = 47\%$ (P = 0.15).

Hospital Stay (Days)

Four studies [11, 12, 21, 23] reported the data of hospital stay duration after cardiac surgery during the use of chest tube (CT versus ATC) (Supplementary Fig. 11). The pooled (unmatched)

Table 2 Shows cardiac surgery status

Study ID	Study arms	Operation status *n* (%)		Coronary artery bypass surgery (CABG) n(%)	Valve replacement *n* (%)	CABG + valve replacement *n* (%)	Cardiopulmonary bypass (CPB) *n* (%)	Chronic obstructive pulmonary disease (COPD) *n* (%)	Other *n* (%)
		Elective Surgery	Non-Elective Surgery						
Baribeau et al. 2019	CT	130 (43%)	172 (57%)	167 (55%)	49 (16%)	38 (13%)	140 (46%)	-	48 (16%)
	ATC	139 (41%)	198 (59%)	192 (57%)	30 (8.9%)	40 (12%)	155 (46%)	-	75 (22%)
Grieshaber et al. 2018	CT	202 (56%)	157 (64%)	-	-	-	-	-	-
	ATC	133 (60%)	89 (40%)	-	-	-	-	-	-
Sirch et al. 2016	CT	1246 (67%)	-	1011 (54.7%)	436 (23.6%)	260 (14.1%)	-	264 (14%)	142 (7.7%)
	ATC	178 (70%)	-	148(57.8%)	65 (25.4%)	20 (7.8%)	-	42 (16%)	23 (9.0%)
St-Onge et al. 2017	CT	138 (87%)	-	93 (59%)	55 (35%)	22 (14%)	-	18 (11%)	-
	ATC	127 (89%)	-	89 (63%)	45 (32%)	17 (12%)	-	26 (18%)	-
St-Onge et al. 2021	CT	110 (42%)	-	182 (69%)	63 (24%)	38 (14%)	-	42 (16%)	-
	ATC	101 (39%)	-	174 (68%)	70 (27%)	42 (16%)	-	48 (19%)	-
Vasileios et al. 2020	CT	1609 (81%)	-	883 (45%)	337 (17%)	235 (12%)	984 (50%)	-	525 (27%)
	ATC	367 (76%)	-	228 (47%)	69 (14%)	51 (11%)	264 (55%)	-	133 (28%)
Malgerud et al. 2020	CT	-	-	-	-	-	-	-	-
	ATC	-	-	-	-	-	-	-	-
Maltais et al. 2016	CT	-	-	-	-	-	-	-	77 (100%)
	ATC	-	-	-	-	-	-	-	175 (100%)

CT, conventional tube; *ATC*, active tube clearance

MD for duration of hospital stay was insignificant between groups (MD = −0.61, 95% $CI = [-1.31, -0.08]$, $P = 0.08$) with heterogeneity $I^2 = 80\%$ ($P = 0.002$). To resolve the heterogeneity, St-Onge et al. [21] was excluded. The pooled estimate

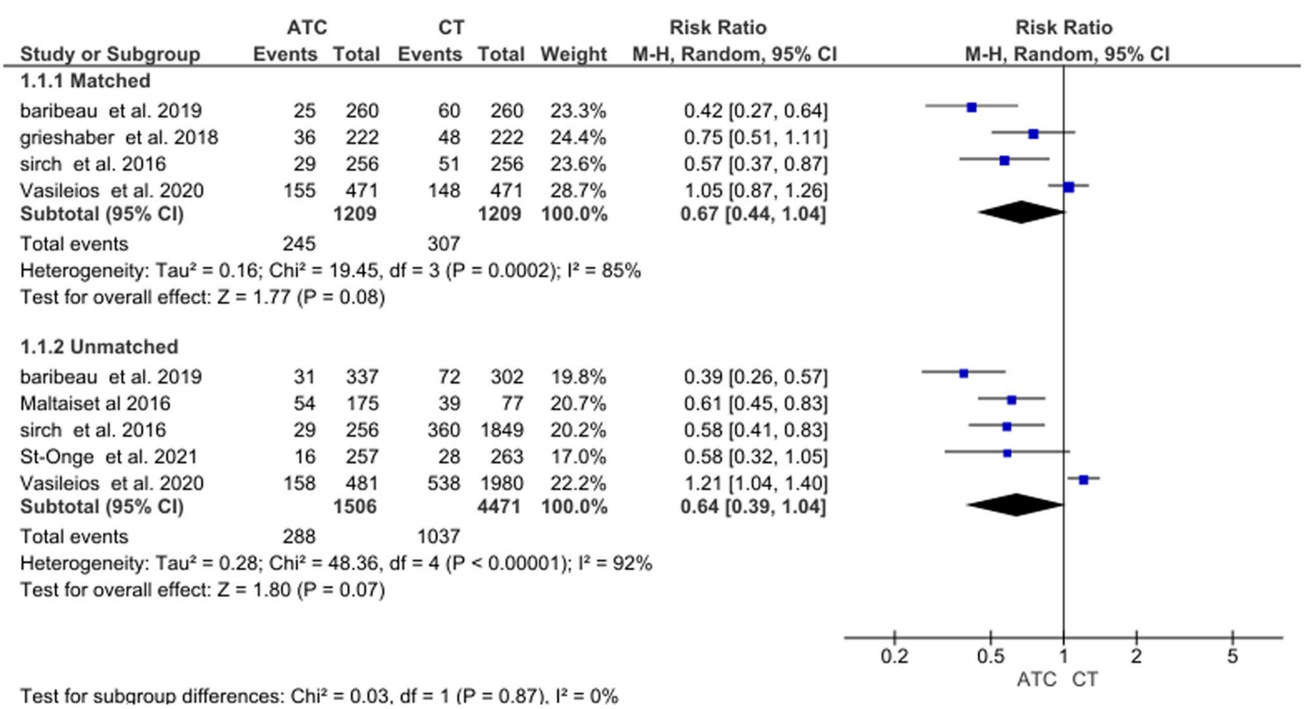

Fig. 2 The pooled risk ratio of Retained Blood (RB) in ATC compared with CT

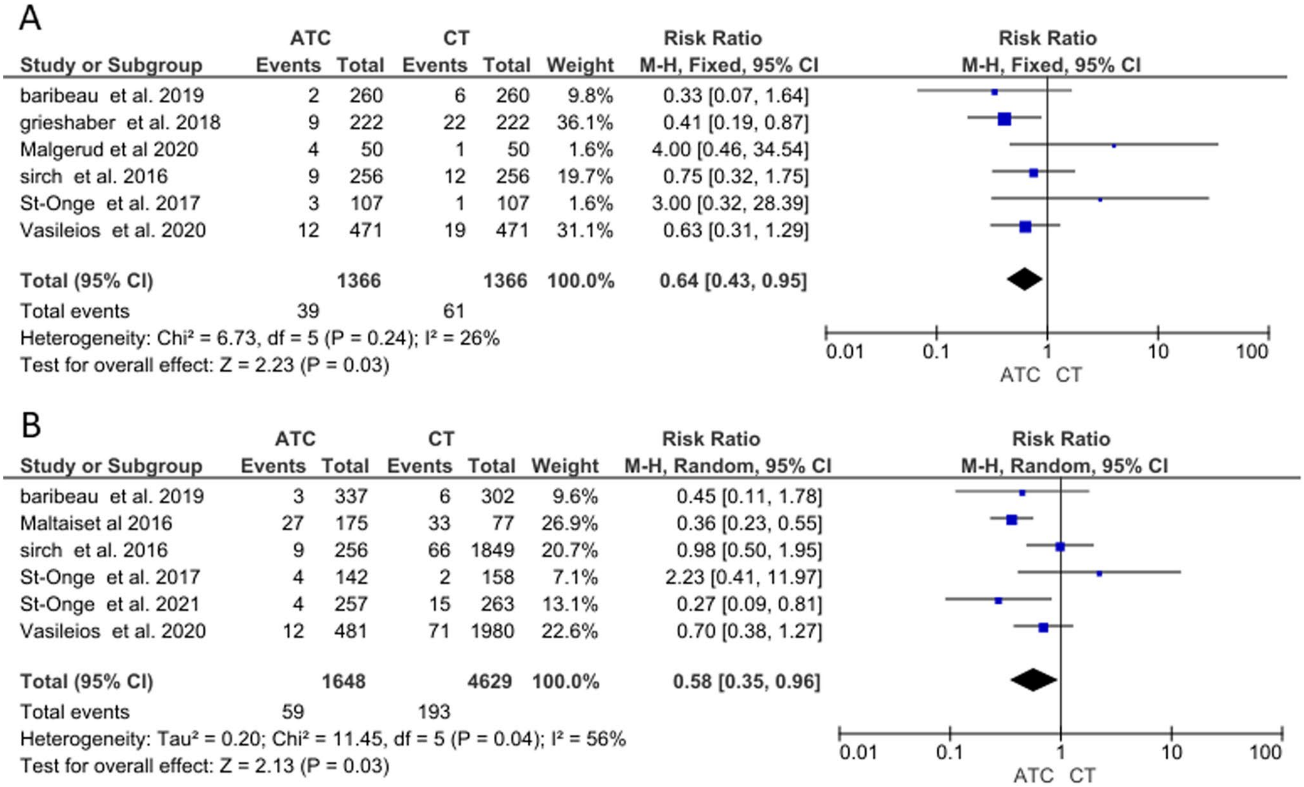

Fig. 3 The pooled risk ratio of Re-exploration in ATC compared with CT

of the remaining three studies [12, 23] showed a significant decrease in hospital stay favoring ATC (MD $= -0.99$, 95% $CI = [-1.35, -0.62]$, $P < 0.00001$) and no heterogeneity $I^2 = 0\%$ ($P = 0.83$) detected.

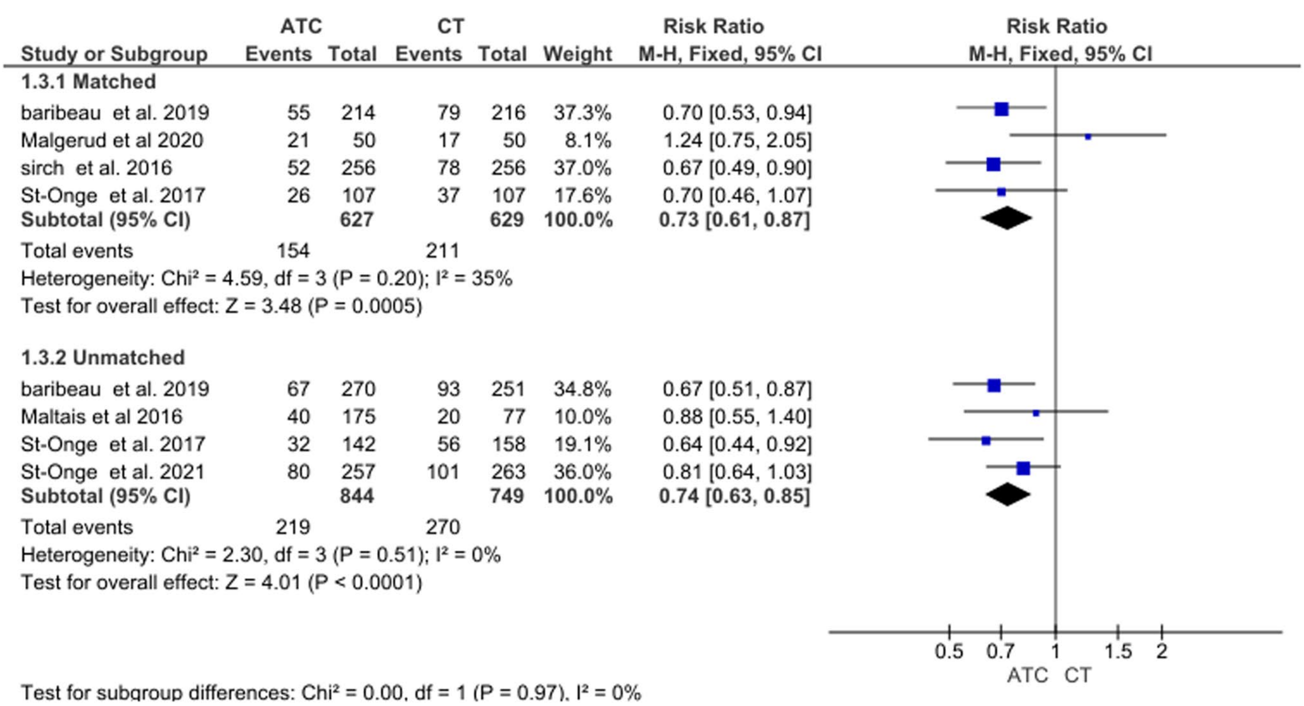

Fig. 4 The pooled risk ratio of Postoperative atrial fibrillation (POAF) in ATC compared with CT

Total Ventilation Time (Hours)

Only three studies [11, 12, 21] reported the total ventilation time in patients with chest tube after cardiac surgery (Supplementary Fig. 12). The results of pooled estimate (unmatched) showed no significant difference between CT and ATC in ventilation time favoring CT (MD = 0.05, 95% *CI* = [−0.35, 0.44], $P = 0.82$) with heterogeneity $I^2 = 40\%$ ($P = 0.19$).

Pneumonia

The data of pneumonia incidence after cardiac surgery was available in only two studies [21, 23] (Supplementary Fig. 13). The pooled (unmatched) results showed a significant decrease in the incidence of pneumonia in ATC group compared with CT group (RR = 0.41, 95% *CI* = [0.21, 0.82], $P = 0.01$) with heterogeneity $I^2 = 66\%$ ($P = 0.08$).

Pleural Interventions

Four studies [12, 13, 21, 23] reported the data of pleural interventions after cardiac surgery (Supplementary Fig. 14). It was found to be significantly improved when the results were pooled favoring the ATC group in matched group (RR = 0.51, 95% *CI* = [0.27, 0.95], $P = 0.03$) and the results were homogenous $I^2 = 54\%$ ($P = 0.11$) (Fig. 14A). It was found to be insignificantly improved in unmatched group (RR = 0.63, 95% *CI* = [0.32, 1.24], $P = 0.18$) and the results were heterogenous $I^2 = 72\%$ ($P = 0.01$) and the heterogeneity was resolved after removing Baribeau et al. [23] and Sirch et al. [13] (RR = 1.57, 95% *CI* = [0.51, 4.8], $P = 0.61$, $I^2 = 26\%$ ($P = 0.21$)).

Pericardial Interventions

Four studies [12, 13, 21, 23] reported the data of precardial intervention (Supplementary Fig. 15). Statistically, there was no difference between the two chest tubes in the pooled RR, regardless of whether the patients were matched (RR = 0.58, 95% *CI* = [0.23, 1.47], $P = 0.25$) or not (RR = 0.57, 95% *CI* = [0.25, 1.29], $P = 0.18$), with insignificant heterogeneity in matched $I^2 = 40\%$ ($P = 0.19$) and unmatched $I^2 = 0\%$ ($P = 0.45$).

Cardiac Tamponade

Two studies [12, 21] reported unmatched data of cardiac tamponade (Supplementary Fig. 16). The pooled (unmatched) results showed an insignificant difference in the incidence of cardiac tamponade in ATC group compared with CT group (RR = 0.46, 95% *CI* = [0.03, 6.85], $P = 0.57$) with heterogeneity $I^2 = 75\%$ ($P = 0.05$).

Pleural Effusion

Four studies [15, 20, 22, 23] reported the data of pleural effusion (Supplementary Fig. 17). Pleural effusion was found to be insignificantly different when the results were pooled in matched group (RR = 0.58, 95% *CI* = [0.29, 1.17], $P = 0.13$) and the results were heterogenous $I^2 = 82\%$ ($P = 0.004$). The detected heterogeneity was resolved by leaving Grieshaber et al. out, and the results became significant (RR = 0.39, 95% *CI* = [0.3, 0.5], $P < 0.00001$, $I^2 = 0\%$ ($P = 0.51$)). Also, it was found to be insignificantly different in unmatched group (RR = 0.62, 95% *CI* = [0.16, 2.37], $P = 0.49$) and the results were heterogenous $I^2 = 99\%$ ($P < 0.00001$).

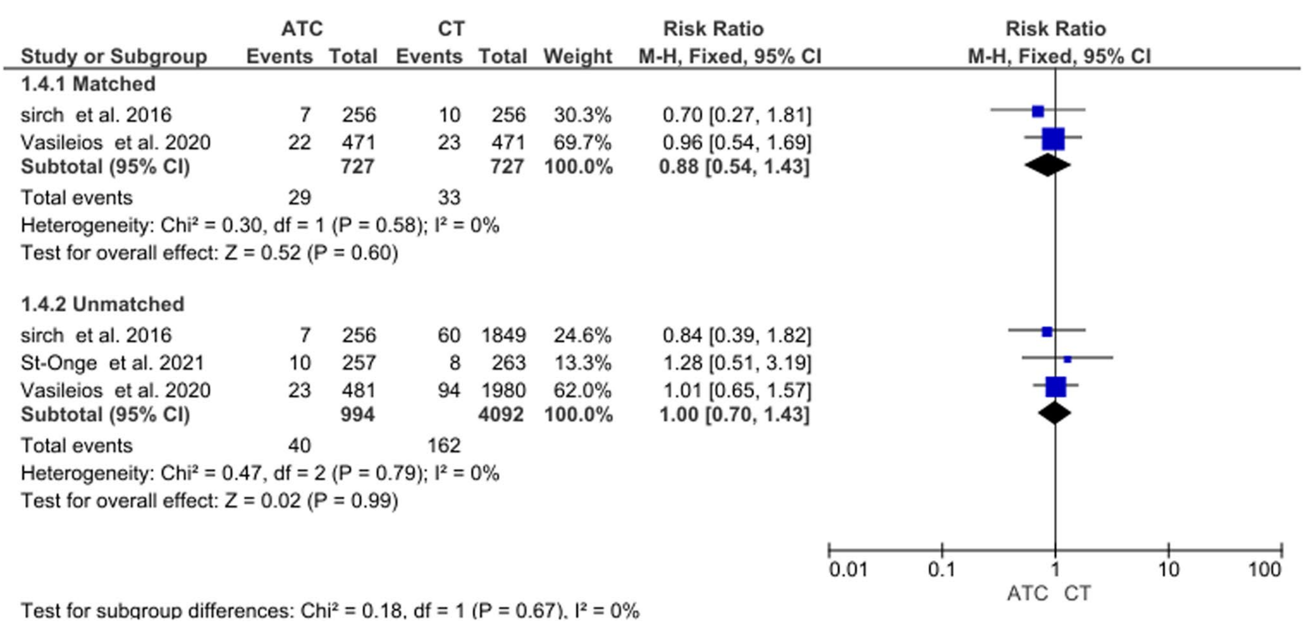

Fig. 5 The pooled risk ratio of Pneumothorax incidence in ATC compared with CT

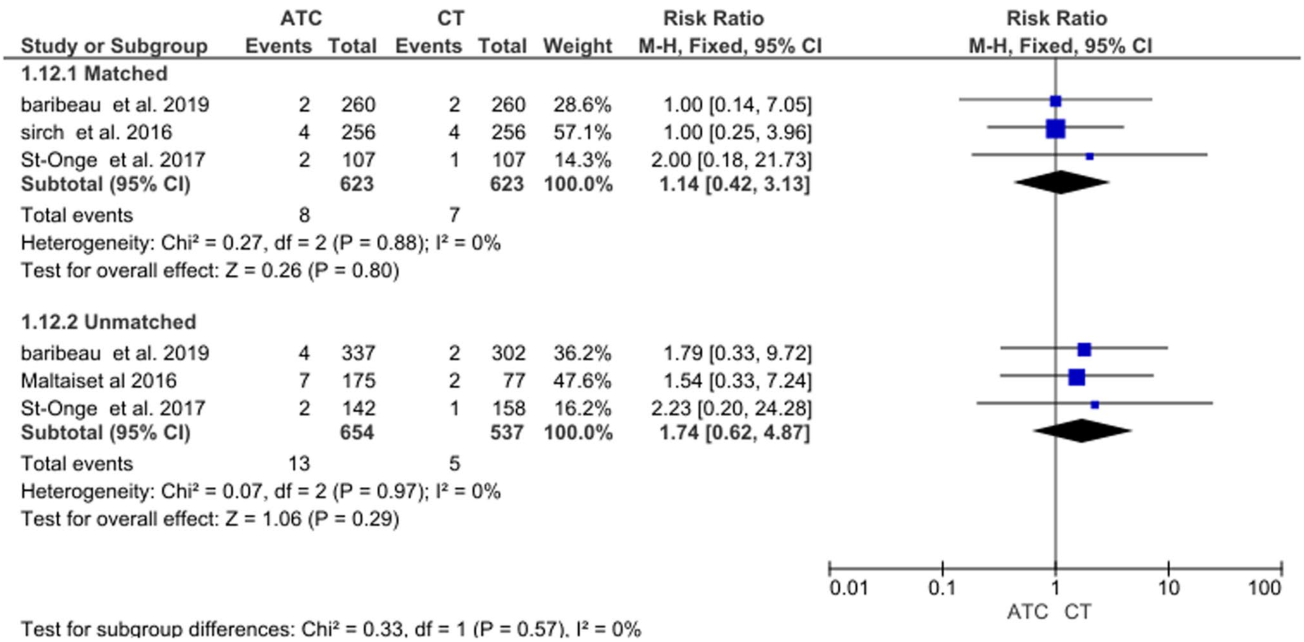

Fig. 6 The pooled risk ratio of Stroke incidence in ATC compared with CT

Sternal Infection

Two studies [15, 21] reported unmatched data of sternal infection (Supplementary Fig. 18). The pooled (unmatched) results showed an insignificant difference in the incidence of sternal infection in ATC group compared with CT group (RR = 0.57, 95% CI = [0.05, 6.38], P = 0.65) with heterogeneity I^2 = 81% (P = 0.02).

Cardiac Arrest

Two studies [11, 12, 21] reported unmatched data of cardiac arrest (Supplementary Fig. 19). The pooled (unmatched) results showed an insignificant difference in the incidence of cardiac arrest in ATC group compared with CT group (RR = 0.97, 95% CI = [0.3, 3.17], P = 0.96) with insignificant heterogeneity I^2 = 22% (P = 0.28).

Discussion

This SR/MAs study is focusing on eight trials; five cohort studies [11–13, 23, 24] and three clinical trials [20–22] including 7003 patients who underwent cardiac surgery. In our meta-analysis, we analyzed the available evidence of included studies regarding the management of chest tubes after cardiac surgery. Our SR/MAs revealed that ATC improves the clinical conditions of cardiac patients and reduces post-surgery complications compared to CT. The statistical comparisons of outcomes between the ATC and CT groups were performed postoperatively and included retained blood, re-exploration, POAF, pneumothorax, stroke, mortality, ICU time, hospital stay, total ventilation time, pneumonia, pleural interventions, pericardial interventions, cardiac tamponade, pleural effusion, sternal infection, and cardiac arrest. Our study revealed that the ATC has more benefits for patients with fewer complications.

The meta-analysis findings demonstrate that cardiac patients in the ATC group have the same risk of RB incidence after surgery compared to CT. The higher RB level reflects an increase in accumulation of blood, blood clot, or fluid after cardiac surgical procedure and this requires a post-operative intervention to drainage the blood clots and fluid using additional chest tube, pericardial drainage, and other interventions [23]. Maltais et al. [11] conveyed that the relevant risk of the retained blood was reduced by 59% in a mechanical assist cohort of patients, also both Baribeau et al. [23] and Sirch et al. [13] reported a 59% and 43% relative risk reduction in the retained blood treated with ATC, respectively.

When it comes to cardiac surgery, POAF is regarded to be a common arrhythmia that happens in anywhere from 10 to 65% of instances, depending on the patient's features, the surgical procedure, and the patient's monitoring [25]. Our SR/MAs exhibited a significant decline in POAF and re-exploration after cardiac surgery after using ATC in comparison with CT. Several studies have linked the incidence of POAF after cardiac surgery with increased risk of heart failure and stroke as well as prolonged ICU and hospital stay and increased mortality [26–29]. Also, other studies confirmed the detrimental relevance of re-explorations and postoperative mortality [22, 30, 31]. This explains the results of our meta-analysis, which showed a significant reduction in the length of hospital stay in the ATC group compared to the CT group. Furthermore, the analysis showed a reduction in the length of ICU stays with ATC, but the results were not significant. However, LaPar et al. [26] reported that the POAF finding could have an impact on reducing the hospital resource utilization, therefore, reducing hospital costs.

According to our results, there has been no significant decline in stroke incidence, mortality rate, total ventilation time, and pneumothorax incidence after cardiac surgery. While the incidence of pneumonia was significantly lesser in the ATC group in comparison with the CT group.

From our included study's findings, Grieshaber et al. [22] concluded that the ATC could not improve the overall survival, but it is linked with reduced re-exploration in patients undergoing cardiac surgery, as it is the only retained blood syndrome (RBS) component related to mortality. Baribeau et al. [23] concluded that ATC has been associated with a reduction in RB, POAF, blood loss, ICU stays, and reduced hospital costs. Sirch et al. [13] pointed out a significant reduction in the interventions for pleural effusions, RBS composite endpoint, and POAF. In 2017, St-Onge [12] reported that the use of an ATC protocol might be associated with reduced POAF. While in 2021, according to St-Onge et al. [21], ATC reduced the need for re-exploration and the likelihood of chest tube obstruction in patients who had had cardiac surgical procedures. In 2020, Vasileios et al. [24] discovered that placing the ATC in a retrosternal position lowered chest tube output without affecting the rate at which patients were treated for retained blood syndrome. In addition, Baribeau et al. [23], Sirch et al. [13], and St-Onge et al. [12] have advocated that the patency of the chest tube should be maintained in the early hours following cardiac surgery in order to improve postoperative outcomes.

Our results revealed that pleural interventions (thoracentesis or supplemental chest tube placed after surgery, thoracotomy or thoracoscopy for hemothorax) and pericardial interventions (pericardial window or pericardiocentesis) after surgery have the same risk in the ATC group compared to CT.

Baribeau et al. [23] showed that 8.1% reduction in plural interventions in ATC group and 22% reduction in CT group and the incidence of pericardial interventions were similar in both groups 4.1%. Sirch et al. [13] reported 12.5% incidence of plural interventions, 1.9% incidence of pericardial interventions in CT group but in ATC group, the incidence was 6.6% in pleural interventions, and 0.4% in pericardial intervention.

St-Onge et al. [12] and St-Onge et al. [21] were the only studies that reported the cardiac tamponade. St-Onge et al. [12] reported that three patients in ATC group and two in CT group developed cardiac tamponade with insignificant difference, but St-Onge [21] reported that the significant lower incidence of cardiac tamponade in ATC group is 0.4% versus 3.4% in CT group. Our analysis revealed that there is no difference between ATC and CT in decreasing incidence of cardiac tamponade after cardiac surgery.

Baribeau et al. [23] reported that ATC was better in the reduction of pleural effusion after cardiac surgery, but Vasileios et al. [24], Grieshaber et al. [22], and Malgerud et al. [20] showed that there is no significant difference between ATC and CT. After pooling these results, there was no difference in decreasing the incidence of pleural effusion.

In St-Onge et al. [21], there were no difference between the two groups in sternal infection and cardiac arrest. Also in Vasileios et al. [24], the ATC and CT were nearly similar in decreasing the incidence of sternal infection. St-Onge et al. [12] and Maltais et al. [11] showed that the ATC and CT did not significantly differ from each other.

To our knowledge, it is the first SR/MAs to compare ATC with CT in patients after cardiac surgery to find out if ATC decreases RBS in a collective series of all participants and then to implement a universal protocol using ATC. For this SR/MAs, we followed the *Cochrane Handbook of Systematic Reviews* and PRISMA checklists.

The limitations were that the meta-analysis is based on the published articles only; non-English, non-indexed, or unpublished articles were not included in our meta-analysis, which may affect our conclusion and raise a possible publication bias. Other study limitations were the small number of the included studies with only three clinical trials (two randomized [20, 21] and one non-randomized [22]), heterogeneity regarding type of cardiac surgery, and no adjustment for demographic and clinical parameters. In addition, some studies [12, 13, 21, 23] received funds or grants or discounts from ClearFlow, Inc., the provider of ATC system (PleuraFlow Active Clearance Technology; Clear Flow, Inc., Anaheim, CA); so, there is a possibility of funding bias. However, these studies declared that the authors had absolute authority over the study design, collection, and entry of data, data analysis, and other study processes. Therefore, we must take these limitations together into consideration during the interpretation of the results. To confirm these observations, additional research is needed.

Conclusion

The clinical findings support the usage of ATC. Patients who underwent active chest tube clearance had lower rates of re-exploration, pneumonia, and postoperative atrial fibrillation as compared to those who underwent conventional chest tube clearance. There was no difference between ATC and CT in the retained blood, pneumothorax, stroke, mortality, urinary tract infection (UTI), ICU time, hospital stay, total ventilation time, pneumonia, plural interventions, pericardial interventions, cardiac tamponade, pleural effusion, sternal infection, and cardiac arrest.

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Data Availability The data that support the findings of this study are available on request from the corresponding author.

Code Availability Not applicable.

Declarations

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Conflict of Interest The authors declare no competing interests.

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