Published in final edited form as:
Interact Cardiovasc Thorac Surg. 2011 June ; 12(6): 919–923. doi:10.1510/icvts.2010.265165.

Preoperative computed tomography is associated with lower risk of perioperative stroke in reoperative cardiac surgery,☆,☆☆

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Abstract

Preoperative computed tomography (CT) use appears to be increasing among patients undergoing cardiac reoperations. We hypothesized that preoperative CT imaging reduces adverse outcomes and operative mortality for these patients. From July 2002 to February 2009, 373 patients underwent cardiac reoperations. Patients were stratified according to those with preoperative CT imaging (CT, n=140) and to those without preoperative CT imaging (NCT) (NCT, n=233). Preoperative risk, operative features, and postoperative outcomes were evaluated. Operative mortality for all cardiac reoperations was 7.5%. Patient risk factors were similar between CT and NCT groups. Preoperative imaging was more commonly performed for reoperative isolated valve operations (CT=70% vs. NCT=55.8%, P=0.01) but less commonly performed for reoperative isolated coronary artery bypass grafting (CABG) operations (14.3% vs. 22.7%, P=0.05). Postoperative renal failure, prolonged ventilation and operative mortality were similar between groups. Importantly, perioperative stroke occurred only within the NCT group (5.6% vs. 0.0%, P=0.003), and emergent operative status [odds ratio (OR): 6.45, confidence interval (CI): 1.15–36.10, P=0.03] as an independent multivariate predictor of perioperative stroke. Thus, preoperative CT imaging is associated with lower rates of perioperative stroke in patients undergoing cardiac reoperations by optimizing cannulation and aortic clamping strategies. Routine use of preoperative CT should be considered for patients undergoing cardiac operations following prior sternotomy.

Keywords

Computed tomography; Reoperation; Cardiac surgery; Stroke

1. Introduction

Performance of cardiac operations after prior sternotomy confers an increased risk of operative mortality and morbidity. According to recent reports, mortality rates remain elevated for a variety of cardiac reoperations, including coronary artery bypass grafting (CABG) and cardiac valve procedures [1–4]. Consequently, efforts directed to improve

☆Presented at the 96th Annual Clinical Congress of the American College of Surgeons, October 3–7, 2010, Washington, DC.

☆☆Funding: This study was supported by Award Number 2T32HL007849-11A1 (DJL) from the National Heart, Lung, and Blood Institute and the Thoracic Surgery Foundation for Research and Education Research Grant (GA, CLL). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Heart, Lung, and Blood Institute or the National Institutes of Health.

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surgical outcomes for patients undergoing cardiac reoperations remain critical in an era of advancing technology.

The use of preoperative imaging for cardiac surgery has been increasingly reported [5–8], and preoperative computed tomography (CT) appears to benefit patients undergoing cardiac reoperations. This technology allows surgeons to survey substernal, mediastinal, and cardiac anatomy to better define existing aberrations, and to aid in preoperative decision analysis and cannulation strategy. Thus, routine use of modern imaging technology offers one approach to improving patient outcomes.

The objectives of this study were to characterize the use of preoperative CT imaging for reoperative cardiac surgery and to examine its role in improving postoperative patient outcomes. We sought to determine whether preoperative CT imaging reduces adverse outcomes and operative mortality for patients undergoing cardiac procedures following prior sternotomy.

2. Methods

2.1. Patients

This study was approved by the University of Virginia Institutional Review Board (HSR# 14077). A retrospective review of all patients undergoing cardiac operations (July 2002–February 2009) with a history of previous sternotomy was conducted using our institution's Society of Thoracic Surgeons (STS) Adult Cardiac Surgery database. Individual radiology reports were reviewed to identify the performance of preoperative CT. Patients were stratified into two study groups: those with routine preoperative CT imaging (CT) and to those without routine preoperative CT imaging (NCT). Patients undergoing cardiac transplantation, ventricular assist device removal or placement, or thoracic aortic aneurysm repair or replacement were excluded from analyses. Established STS database definitions were utilized for all preoperative variables, postoperative complications and outcomes. All patient outcomes of interest were established a priori before data collection. Operative mortality was defined as patient deaths occurring prior to hospital discharge or within 30 days of operation. Major complications included the composite incidence of postoperative mortality, stroke, renal failure, and new-onset hemodialysis.

2.2. Statistical analysis

Primary outcomes of interest were the incidence of operative mortality and postoperative complications. Observed differences in patient and operative characteristics as well as outcomes between study groups were determined using appropriate hypothesis testing. Categorical variables were compared using either Pearson's χ^2 or Fisher's exact tests, and continuous variables were compared using Student's *t*-test for normally distributed or the Mann–Whitney *U*-test for non-normally distributed data where appropriate. In addition, univariate and multivariate analyses of risk factors associated with the outcome of stroke were performed. For multivariable logistic regression, model performance was assessed by the area under the receiver operator characteristics (AUC) curve and the Hosmer–Lemeshow test.

All categorical variables are expressed as within group percentages, and continuous variables are expressed as either means±standard deviation (S.D.) or median [inter-quartile range]. Adjusted odds ratio (OR) with a 95% confidence interval (CI) are used to report the results of multivariable logistic regression analyses. All reported *P*-values are two-tailed, and statistical significance was indicated by $P<0.05$. Data analysis was performed using SPSS software, version 17 (SPSS, Chicago, IL, USA).

3. Results

3.1. Comparison of patient characteristics and preoperative risk factors

Univariate analyses of patient risk factors are displayed in Table 1. Over the 7.5-year study period, a total of 373 patients undergoing cardiac reoperations met clinical criteria for inclusion in our analyses. Within this cohort, 140 patients underwent cardiac reoperations with preoperative CT imaging, and 233 patients underwent operations without preoperative CT imaging. The average patient age was similar between CT and NCT groups. The CT group included slightly fewer female patients (31.4%) compared to the NCT group (33.5%); however, this difference was not statistically significant. The incidence of major cardiac surgical risk factors included: peripheral vascular disease (16.6%), cerebrovascular disease (23.1%), diabetes (28.4%), heart failure (46.6%), and renal failure (12.6%). Preoperative stroke rates were similar between CT (12.9%) and NCT (12.4%, $P>0.99$) groups. Indications for previous sternotomy were also similar between study groups.

3.2. Comparison of operative features for CT and NCT patients

Operative features for patients undergoing cardiac reoperations are detailed in Table 2. The performance of isolated CABG operations occurred in 22.7% of NCT patients and in 14.3% of CT patients ($P=0.05$). CT patients underwent a higher percentage of isolated valve procedures (70.0% vs. 55.8%, $P=0.01$). Cardiopulmonary bypass cannulation techniques were similar between study groups. Performance of urgent and emergent operations occurred in 33% of CT patients and in 30% of NCT patients. Intraoperative transfusion requirements as well as cardiopulmonary bypass time were similar despite the use of preoperative CT imaging.

3.3. Comparison of postoperative outcomes for CT and NCT patients

Few differences in postoperative outcomes were observed between study groups (Table 3). Overall, operative mortality was 7.3% for NCT patients and 7.9% for CT patients ($P=0.84$). The composite incidence of major complications was higher among NCT patients (17.6%) compared to CT patients (10.7%, $P=0.08$); however, this trend did not reach statistical significance. Similarly, incrementally higher rates of postoperative arrhythmias, cardiac arrest, prolonged ventilation, renal failure and new onset hemodialysis were observed for NCT patients. However, postoperative strokes occurred only within the NCT group (5.6% vs. 0.0%, $P=0.003$).

3.4. Influence of preoperative and operative risk factors on postoperative stroke

Univariate associations of risk factors and the outcome of postoperative stroke appear in Table 4. Postoperative strokes were more common among males, patients with preoperative hemodialysis requirements, and those undergoing emergent operations. The prevalence of preoperative stroke was not different between groups on subset analysis. In addition, strokes occurred in 23.1% of patients undergoing CABG+ valve procedures.

Multivariable logistic regression analysis further identified emergent operative status (OR: 6.45, CI: 1.15–36.10, $P=0.03$) as an independent predictor of postoperative stroke. The model risk adjusted for the confounding influence of age, gender, cardiac reoperation type, operative status (elective, urgent, emergent), cardiopulmonary bypass cannulation site, and use of preoperative CT. The statistical model achieved adequate discrimination with an AUC=0.798 and Hosmer–Lemeshow P-value=0.07.

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4. Discussion

The present study demonstrates the efficacy of routine preoperative CT for patients undergoing cardiac operations following previous sternotomy. In a cohort of 373 reoperative cardiac surgery patients, use of preoperative CT imaging was associated with similar operative mortality, lower incidence of composite major complications, and markedly reduced postoperative stroke rates. Performance of preoperative CT imaging was more commonly performed prior to isolated valve procedures and less commonly performed for reoperative CABG. In addition, prior indication for sternotomy did not correlate with preoperative CT imaging practices. Overall, these results bolster those of previous studies and highlight the perioperative benefit of preoperative CT for the optimal planning and performance of cardiac reoperations in the face of a prior sternotomy.

Reoperative cardiac surgery has become increasingly more common in recent years and is associated with elevated morbidity and mortality. These cases often present inherent technical challenges of mediastinal adhesions and an increased risk of injury upon re-entry or to previously placed bypass grafts. In addition, it may disrupt cardiopulmonary bypass cannulation and myocardial protection efforts [9, 10]. While injury to previously placed coronary grafts has been associated with high perioperative myocardial infarction rates (40%) and elevated mortality (8%–12%) [11], the implications of sternal re-entry injuries remains unsettled. In the present study, right ventricle (RV) injuries occurred only among those without preoperative CT imaging (*n*=4y233, 1.7%). In addition, injury to the RV in each case was not associated with an increased mortality and morbidity in this study.

The use and benefits of preoperative CT for cardiac reoperations appears to be increasing [5, 6, 8, 12]. Cremer and colleagues demonstrated a 98% safe re-entry rate and low injury rate (2%) in their study of patients undergoing reoperative CABG [6]. Other series have reported on the role of preoperative CT imaging and the development of alternate surgical strategies [5, 6, 12]. In fact, adoption of alternative surgical strategies has been documented to occur in up to 80% of cases, resulting in a significant reduction in the risk of re-entry injuries and mortality [5, 8, 12]. In one of the largest series, the benefits of establishing cardiopulmonary bypass via peripheral cannulation prior to sternotomy was demonstrated in the setting of dense retrosternal adhesions identified by preoperative CT [13]. These benefits were consistent with those of the present study.

In this study, we originally postulated that preoperative CT imaging would be associated with reduced adverse outcomes and operative mortality for reoperative cardiac procedures. As a result, we found that operative mortality rates were similar between CT and NCT groups, while major complication rates for patients undergoing reoperations with preoperative CT imaging were improved by 7% compared to those without CT-scans. Although this improvement did not achieve statistical significance, the perioperative benefits derived from preoperative imaging likely reflect alterations in surgical strategy in these patients. In our cohort, the selection of cannulation site and clamping strategy was largely influenced by CT-scan findings. Although the distribution of cannulation strategies were similar between groups, we believe that the preoperative assessment of existing retrosternal anatomy and aortic architecture by routine CT imaging resulted in more appropriate selection of cannulation sites and surgical management, resulting in the 0.0% stroke rate within our CT group.

We observed significantly improved perioperative stroke rates among patients undergoing preoperative CT imaging prior to cardiac reoperations. In fact, postoperative strokes occurred only among NCT patients (*n*=13, 5.6%). We believe this difference in stroke rates is largely due to benefits of preoperative CT imaging to allow for a more thorough evaluation of aortic architecture and the distribution of aortic calcifications, which we believe translated into improved selection of cannulation and clamping sites to minimize the risk of aortic plaque disruption and subsequent strokes. In fact, in a previous prospective study of 921 consecutive elective cardiac surgery patients, atherosclerotic disease in the ascending aorta was associated with an 8.7% incidence of postoperative stroke compared to 1.8% in patients without atherosclerosis (P<0.0001) [14]. Furthermore, univariate correlates of postoperative stroke in the present study included male gender, preoperative hemodialysis requirements, and performance of CABG+ valve procedures or emergent operations, and emergent (or unstable) operative status independently increased the risk of perioperative stroke (OR=6.45, P=0.03) on multivariate analysis. These results were not surprising as they often represent high risk reoperative scenarios, and, in cases of emergent operations, those in which the benefits of preoperative CT could not be utilized. In fact, it is likely the effect modification of emergent operative status that resulted in a non-significant association between the use of preoperative CT and postoperative stroke. Nevertheless, the measured associations related to the performance of cardiac reoperations and postoperative stoke in this series are consistent with those reported elsewhere [15].

To our knowledge, this study represents one of the largest series examining postoperative stroke rates as a function of preoperative CT utilization. Thus, our results are hypothesis generating and provide a basis for future prospective studies to evaluate the influence of alternative cannulation strategies in response to preoperative CT findings and their effect on perioperative stroke. Additionally, we believe our data support the adoption of routine preoperative imaging for cardiac reoperations and should be considered for most cases.

Despite our results, this study has noteworthy limitations. First, the retrospective design introduces inherent selection bias. Second, the admittedly small sample size limits our ability to detect small, statistical differences between CT and NCT groups. In addition, this study reports short-term, operative outcomes. Finally, the low incidence of postoperative stroke following cardiac reoperations limited our statistical modeling efforts to more clearly identify statistically significant multivariate predictors of stroke. Nevertheless, the markedly reduced stroke rates for patients undergoing reoperative cardiac procedures following preoperative CT imaging provide an important clinical contribution to current cardiac surgical literature.

5. Conclusions

Although preoperative CT imaging does not affect operative mortality, it is associated with lower rates of perioperative stroke in patients undergoing reoperative cardiac surgery. Use of routine preoperative CT optimizes choice in cannulation site and clamping strategy to minimize stroke rates and should be performed for patients undergoing reoperative cardiac operations.

Acknowledgments

We thank Curtis Klann and Judy Smith for their assistance with the STS database search and data collection.

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Table 1

Preoperative and risk factors for patients undergoing reoperative cardiac operations without preoperative imaging compared to those with preoperative imaging (*n*=373)

Variables	Preoperative CT (*n*=140)	No preoperative CT (*n*=233)	*P*-value
Preoperative			
Age at operation (years)	61.6±17.1	61.9±15.8	0.81
Sex (male)	96 (68.6%)	155 (66.5%)	0.73
Peripheral vascular disease	19 (13.6%)	43 (18.5%)	0.25
Cerebrovascular disease	34 (24.3%)	52 (22.3%)	0.70
Stroke	18 (12.9%)	29 (12.4%)	>0.99
Diabetes	45 (32.1%)	61 (26.2%)	0.24
Dyslipidemia	95 (67.9%)	164 (70.4%)	0.64
Hypertension	97 (69.3%)	172 (73.8%)	0.34
NYHA class			
Class I	31 (22.1%)	52 (22.3%)	>0.99
Class II	42 (30.0%)	68 (29.2%)	0.91
Class III	37 (26.4%)	50 (21.5%)	0.31
Class IV	30 (21.4%)	63 (27.0%)	0.27
Heart failure	64 (45.7%)	110 (47.2%)	0.83
Endocarditis	11 (7.9%)	21 (9.0%)	0.85
Renal failure	14 (10.0%)	33 (14.2%)	0.26
Hemodialysis	6 (4.3%)	9 (3.9%)	>0.99
Arrhythmia (heart block)	1 (0.7%)	7 (0.4%)	0.92
Arrhythmia (atrial fibrillation)	8 (5.7%)	13 (5.6%)	0.96
Arrhythmia (ventricular)	0 (0.0%)	0 (0.0%)	NA
Ejection fraction (%)	47.7±12.7	47.4±12.2	0.83
Primary operation – CABG only	54 (38.6%)	106 (45.5%)	0.20
Primary operation – CABG+ valve	5 (3.6%)	15 (6.4%)	0.34
Primary operation – valve only	43 (30.7%)	58 (24.9%)	0.23
Primary operation – other	36 (25.7%)	46 (19.7%)	0.20

CT, Computed tomography; NYHA, New York Heart Association; CABG, coronary artery bypass grafting.

Table 2

Operative characteristics for patients undergoing reoperative cardiac operations without preoperative imaging compared to those with preoperative imaging (*n*=373)

Variables	Preoperative CT (*n*=140)	No preoperative CT (*n*=233)	*P*-value
CABG only	20 (14.3%)	53 (22.7%)	0.05
CABG+ valve procedure	14 (10.0%)	33 (14.2%)	0.26
Valve procedure	98 (70.0%)	130 (55.8%)	0.01
Other procedure	9 (6.4%)	16 (6.9%)	>0.99
Cardiopulmonary bypass cannulation			
Aorta and atrial caval	130 (92.9%)	205 (88.0%)	0.16
Aorta and femoral jugular	0 (0.0%)	3 (1.3%)	0.30
Femoral artery and atrial caval	1 (0.7%)	6 (2.6%)	0.26
Femoral artery and femoral jugular	3 (2.1%)	9 (3.9%)	0.55
Other	6 (4.3%)	8 (3.4%)	0.78
Elective operative status	94 (67.1%)	163 (70.0%)	0.57
Urgent operative status	43 (30.7%)	56 (24.0%)	0.18
Emergent operative status	3 (2.1%)	14 (6.0%)	0.12
Intraoperative blood products transfused			
Packed red blood cells (units)	1.2±1.8	1.1±2.1	0.44
Fresh frozen plasma (units)	1.7±2.3	1.6±2.2	0.73
Platelets (units)	0.6±0.7	0.7±0.8	0.56
Cryoprecipitate (units)	0.2±0.5	0.2±0.5	0.77
Cardiopulmonary bypass time (min)	128.3±53.8	129.1±53.3	0.60
Aortic cross-clamp time (min)	83.7±34.0	85.8±35.9	0.89

CT, Computed tomography; CABG, coronary artery bypass grafting.

Table 3

Postoperative complications and outcomes for patients undergoing cardiac reoperations without preoperative imaging compared to those with preoperative imaging (*n*=373)

Variables	Preoperative CT (*n*=140)	No preoperative CT (*n*=233)	*P*-value
Sepsis	2 (1.4%)	7 (3.0%)	0.49
Stroke	0 (0.0%)	13 (5.6%)	0.003
Perioperative myocardial infarction	1 (0.7%)	2 (0.9%)	>0.99
Reoperation for bleeding/tamponade	7 (5.0%)	11 (4.7%)	>0.99
Atrial fibrillation	18 (12.9%)	35 (15.0%)	0.65
Heart block	2 (1.4%)	9 (3.9%)	0.22
Cardiac arrest	5 (3.6%)	12 (5.2%)	0.61
Gastrointestinal event	5 (3.6%)	5 (2.1%)	0.51
Pneumonia	10 (7.1%)	18 (7.7%)	>0.99
Prolonged ventilation	25 (17.9%)	51 (21.9%)	0.43
Renal failure	8 (5.7%)	24 (10.3%)	0.18
Hemodialysis (new onset)	6 (4.3%)	16 (6.9%)	0.37
Major complications	15 (10.7%)	41 (17.6%)	0.08
Operative mortality	11 (7.9%)	17 (7.3%)	0.84

CT, Computed tomography.

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Table 4

Univariate analyses of preoperative and operative characteristics for the outcomes of stroke following cardiac reoperations (*n*=373)

Variables	**Stroke (*n*=13)**	**No stroke (*n*=360)**	***P*-value**
Preoperative			
Age at operation (years)	62.3±14.0	62.3±16.4	0.83
Sex (female)	12 (92.3%)	239 (66.4%)	0.07
Peripheral vascular disease	2 (15.4%)	60 (16.7%)	)0.99
Cerebrovascular disease	3 (23.1%)	83 (23.1%)	>0.99
Stroke	1 (7.7%)	46 (12.8%)	0.99
Diabetes	2 (15.4%)	104 (28.9%)	0.37
Dyslipidemia	9 (69.2%)	250 (69.4%)	>0.99
Hypertension	10 (76.9%)	259 (71.9%)	>0.99
NYHA class			
Class III	2 (15.4%)	85 (23.6%)	0.74
Class IV	4 (30.8%)	89 (24.7%)	0.74
Heart failure	9 (69.2%)	165 (45.8%)	0.16
Endocarditis	2 (15.4%)	30 (8.3%)	0.31
Renal failure	1 (7.7%)	46 (12.8%)	>0.99
Hemodialysis	2 (15.4%)	13 (3.6%)	0.09
Ejection fraction (%)	42.7±13.2	47.7±12.3	0.16
Operative			
Operation			
CABG only	0 (0.0%)	73 (20.3%)	0.08
CABG+ valve procedure	3 (23.1%)	44 (12.2%)	0.22
Valve procedure	9 (69.2%)	219 (60.8%)	0.77
Other procedure	1 (7.7%)	24 (6.7%)	0.60
Cardiopulmonary bypass cannulation			
Aorta and atrial caval	11 (84.6%)	324 (90.0%)	0.63
Aorta and femoral jugular	0 (0.0%)	3 (0.8%)	>0.99
Femoral artery and atrial caval	1 (7.7%)	6 (1.7%)	0.22
Femoral artery and femoral jugular	0 (0.0%)	12 (3.3%)	0.99
Other	1 (7.7%)	13 (3.6%)	0.40
Operative status			
Elective	6 (46.2%)	251 (69.7%)	0.12
Urgent	4 (30.8%)	95 (26.4%)	0.75
Emergent	2 (23.1%)	14 (3.9%)	0.02

NYHA, New York Heart Association; CABG, coronary artery bypass grafting.