
Cardiac Injury During Resternotomy Does Not Affect Perioperative Mortality

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- BACKGROUND:** Cardiac injury at the time of resternotomy is a complication faced by all cardiac surgeons, although little is known about its effects on morbidity and mortality. This study was designed to address these questions.
- STUDY DESIGN:** Resternotomies performed at the University of Virginia from 1996 to 2005 were identified. Operative notes were reviewed, and any injury during resternotomy to the heart, great vessels, or bypass grafts was recorded. Perioperative complications and mortality were recorded using the Society of Thoracic Surgeons National Database.
- RESULTS:** In the 11-year period studied, 612 resternotomies were performed out of 7,872 total adult cardiac procedures (7.8%). Fifty-six patients (9.1%) had an injury sustained during resternotomy and initial dissection. Injury to grafts was most common (46.4%), with mammary arteries comprising 21% of the total and vein grafts, 25%. The right ventricle was the second most commonly injured structure (21.4%). There were no significant differences in overall nonadjusted mortality in the injured group compared with that in the noninjured group (8.9% versus 10.2%, $p = 0.66$). Multivariate analysis demonstrated third-time resternotomy to be an independent risk factor for cardiac injury ($p = 0.04$).
- CONCLUSIONS:** Cardiac injury at the time of resternotomy is not associated with an increase in perioperative morbidity or mortality. Third-time resternotomy is an independent risk factor for cardiac injury, so vigilance and adequate preparation are paramount in these patients. (*J Am Coll Surg* 2008;206:993–999. © 2008 by the American College of Surgeons)
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Approximately 10% of all adult cardiac operations currently done involve resternotomy.¹ With improving outcomes, patients who have undergone cardiac surgery continue to live longer. So surgeons will inevitably face an increasing number of reoperations. It is well known that redo cardiac surgery is technically more difficult and is fraught with higher morbidity and mortality than first-time operations. More specifically, cardiac injury at the time of resternotomy is one pitfall that must be faced.

Hemorrhage at the time of resternotomy has been reported to occur in up to 8% of resternotomies.¹ When catastrophic hemorrhage occurs, it can increase surgical mortality rates up to 56%.² Given the high morbidity of this complication, a number of techniques have been de-

scribed to increase the safety of sternal entry, such as the use of direct vision, a Stryker or microoscillating saw, presternotomy femoral bypass, pulling up on sternal wires, and thoracoscopy.^{1,3-5}

Regardless of the way in which sternal reentry is gained, injury is inevitable, and a number of unanswered questions remain about this issue. First, what are the risk factors for cardiac injury at the time of resternotomy? It has been suggested that third- and fourth-time resternotomies are independent risk factors for cardiac injury.⁶ Other factors, such as a graft that crosses the midline, conduits, or aortic aneurysm, have also been thought to be risk factors.^{1,7} Second, do patients who incur a cardiac injury have higher morbidity and mortality rates, and, more specifically, are there certain types of injuries (eg, to a live coronary graft) that portend a worse outcome than others? And, finally, are there any data to suggest that putting a patient on bypass preoperatively would decrease the incidence of injury? It has been reported that approximately 40% of cardiac surgeons will initiate bypass before sternotomy in patients who are believed to be high risk.¹

The few previous studies on this subject have examined the effects of “catastrophic hemorrhage” at the time of ster-

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Table 1. Reoperations Performed

Procedure	n	%
CABG	250	40.8
Valve	231	37.7
CABG + valve	64	10.4
Aorta	37	6.0
VAD	11	1.8
Other	19	3.1
Total	612	100.0

CABG, coronary artery bypass grafting; VAD, ventricular assist device.

notomy. This was described as exsanguination at the time of resternotomy, requiring blood products.¹ Although it is difficult to discern whether or not bleeding at the time of resternotomy would be responsible for the use of additional blood products, we believed it was more accurate to describe catastrophic hemorrhage as bleeding during resternotomy that necessitated placement of the patient on urgent cardiopulmonary bypass through alternate cannulation strategies. The aim of this article was to look at all injuries that occurred during resternotomy, rather than just those that could be considered catastrophic.

We generated three hypotheses to address these questions. First, we suggested that cardiac injury at the time of resternotomy would increase morbidity and mortality and that injury to live coronary grafts would be associated with even higher morbidity compared with other injuries. Second, we predicted that multiple reoperations would be a risk factor for injury.⁶ Third, we hypothesized that placing patients on bypass before sternotomy would decrease the chance of injury.

METHODS

This study was approved by the by Human Investigations Committee (HIC), University of Virginia Health System. Using our institution's Society of Thoracic Surgeons database, we identified all reoperations that were performed from July 1995 to June 2006. A reoperation is defined as any operation that occurs at least 30 days after the original operation. We excluded patients undergoing heart trans-

Table 3. Third Sternotomy

Operation	n	%
Valve	26	52.0
CABG	9	18.0
CABG + valve	8	16.0
Aorta	4	8.0
VAD	2	4.0
Congenital	1	2.0
Total	50/612 (8.1%)	100.0

CABG, coronary artery bypass grafting; VAD, ventricular assist device.

Table 2. Second Sternotomy

Operation	n	%
CABG	240	43.2
Valve	202	36.4
CABG + valve	54	9.7
Aorta	32	5.8
VAD	9	1.6
Other	18	3.2
Total	555/612 (90%)	100.0

CABG, coronary artery bypass grafting; VAD, ventricular assist device.

plantation, because we thought that injury to the explanted heart would not necessarily be associated with higher morbidity. Given the fact that this database is of adult cardiac operations, it does not include congenital heart operations unless the patient had undergone a congenital heart operation in the past.

Operative notes for all patients were obtained and thoroughly reviewed. Any mention of an injury at the time of sternotomy or initial dissection before cannulation sutures were placed was considered an injury. Preoperative risk factors and all postoperative complications were recorded prospectively using the criteria defined by the Society of Thoracic Surgeons Adult Cardiac Surgery Database.

The surgical technique for patients undergoing redo cardiac surgery at the University of Virginia includes a thorough preoperative evaluation. Patients who have undergone previous coronary artery bypass grafting (CABG) have a repeat catheterization so that patent bypass vessels can be visualized and adherence to the sternum noted. If a patient is undergoing a third- or fourth-time resternotomy, CT is obtained to assess the proximity of the right ventricle and great vessels to the sternum. Intraoperative conduct involves placement of a femoral arterial line through which to place an arterial cannula using the Seldinger technique if urgent bypass is needed. The anesthesia and pump teams are ready to go emergently on bypass while sternotomy is performed. We use an oscillating saw to divide the anterior table of the sternum, followed by division of the posterior sternum with Mayo scissors.

Statistical analysis was performed using SPSS software (SPSS, Inc). Univariate analysis of categorical variables was done using Fisher's exact test, and Student's *t*-test was used for numerical variables. A Wald forward stepwise logistical regression analysis was performed using variables that had a *p* value ≤ 0.025 or lower by univariate analysis.

RESULTS

We studied 7,872 adult cardiac procedures performed at the University of Virginia during an 11-year period. Excluding resternotomies for transplantation, there were 612

Table 4. Fourth Sternotomy

Procedure	n	%
Valve	4	57.1
Aorta	1	14.3
CABG	1	14.3
CABG + valve	1	14.3
Total	7/612 (1.1%)	100.0

CABG, coronary artery bypass grafting.

resternotomies (7.8%) performed. A majority of the cases were evenly divided between coronary artery bypass surgery (CABG, 40.8%) and valve operations (37.7%; Table 1). The remainder of the procedures were CABG + valve (10.4%), aortic operations (6%), and other procedures that did not fall into the first 4 major categories. A majority of the operations (555 of 612; 90%) performed were second-time sternotomies (Table 2). A smaller percentage (50 of 612; 8.1%) were third-time sternotomies (second redo) but were much more likely to be valve operations (52%). Seven patients (1.1%) had a fourth-time or greater sternotomy (Tables 3, 4).

A total of 56 (9.1%) patients had an injury at the time of resternotomy and initial dissection. Eleven patients (19% of the injury group, 1.8% of the total resternotomy group) had hemorrhage significant enough to require urgent femoral cannulation and bypass. There were no deaths in this subgroup of patients.

The most commonly injured structure was a patent coronary artery bypass graft (26 of 56; 46%), with the right ventricle the second most common structure injured (12 of 56; 21.4%), and the great vessels third (10 of 56; 10%; Table 5).

A majority of the patients (548 of 612; 89.5%) were cannulated in a standard fashion, with the arterial cannula in the aorta and the venous cannula in the atrium (Table 6). The remainder of the patients had femoral or axillary cannulation, and six patients underwent off-pump surgery.

Hypothesis 1: Cardiac injury at the time of resternotomy increases morbidity and mortality, and injury to live coronary grafts is associated with a higher morbidity compared with other injuries

Cardiac injury was not associated with a higher mortality rate in our group, with 5 deaths in the cardiac injury group

Table 6. Methods of Cannulation

Method	n	%
Chest	548	89.5
Femoral	47	7.7
Axillary	11	1.8
Off pump	6	1.0
Total	612	100.0

Table 5. Injuries

Site of injury	n	% of injuries
Graft	26	46.4
Mammary	12	21.4
Vein graft	11	19.6
Vein graft and other	3	5.4
Right ventricle	12	21.4
Great vessels	10	17.9
Right atrium	4	7.1
Right coronary artery	2	3.6
Other	2	3.6
Total	56	100.0

(8.9%) and 51 deaths in the group that did not have cardiac injury (9.2%; Table 7). The five deaths in the cardiac injury group consisted of one patient with a right ventricle injury, one with a right atrium injury, one with a mammary injury, one patient who had both aortic and pulmonary artery injuries, and one patient who had a pulmonary artery and a right coronary artery injury. Of note, two of the four patients who had pulmonary artery injury died. Univariate analysis of preoperative risk factors demonstrated that a history of renal failure and a diagnosis of congestive heart failure were independent risk factors for perioperative mortality. Cardiac injury did not result in higher mortality rates.

Perioperative complications that were recorded in the database included deep and superficial sternal infection, stroke, perioperative myocardial infarction, reoperation for bleeding, cardiac arrest, tamponade, pneumonia, renal failure, aortic dissection, graft occlusion, valvular dysfunction, adult respiratory distress syndrome, and pulmonary embolism. There were no significant differences between the injured and noninjured patients with regard to any of these complications. But mean perfusion time was longer in the injury group (176 minutes \pm 9 [SEM] versus 141 minutes \pm 3 SEM, $p = 0.001$). There was no difference in mortality in the subgroup of patients with injury to live coronary grafts (1 of 26; 3.8% versus 4 of 30; 13.3%, $p = 0.36$). Of note, there were no perioperative myocardial infarctions in any patients in the cardiac injury group.

Hypothesis 2: Multiple reoperations would be a risk factor for injury

Univariate analysis was performed to assess for independent risk factors for perioperative injury. Variables included

Table 7. Cardiac Injury and Mortality

Cardiac injury	Death		p Value
	n	%	
Yes	5/56	8.9	1.0
No	51/556	9.2	

Table 8. Multivariate Analysis of Risk Factors for Cardiac Injury

Risk factor	n	%	Odds ratio	95% CI	p Value
Hyperlipidemia	45/360	11.1	2.5	1.2, 4.9	0.012
Third sternotomy	6/50	12	1.8	0.7, 4.6	0.21
Fourth sternotomy	2/6	33	6.44	1.1, 37.8	0.04
Fifth sternotomy	0/1	0.00			1.0

previous valve surgery, history of myocardial infarction, previous CABG surgery, gender, smoking history, congestive heart failure, renal failure, peripheral vascular disease, infectious endocarditis, hypertension, diabetes, hyperlipidemia, and third-, fourth-, and fifth-time sternotomies. Interestingly, although previous CABG surgery was not a risk factor, a history of hyperlipidemia was found to be an independent risk factor for injury. Multivariate analysis found hyperlipidemia and fourth-time sternotomy to be independent risk factors for cardiac injury at the time of resternotomy (Table 8).

Hypothesis 3: Placing patients on bypass before sternotomy would decrease the risk of injury

Fifteen patients (1%) were placed on cardiopulmonary bypass before sternotomy in this group; there were 2 injuries (2 of 15; 13%). Compared with the group of patients that had sternotomy first, there was no significant difference in injury (13% versus 9%, $p = 0.63$). So in our series, placing patients on cardiopulmonary bypass before sternotomy did not appear to decrease the risk of injury.

DISCUSSION

Injury of the heart and its surrounding structures is an unfortunate but inevitable complication that all cardiac surgeons will face at some time during reoperative surgery. The incidence of this occurrence is not well known and is likely underreported.¹ Although catastrophic hemorrhage is traditionally thought to be associated with high rates of mortality, it is not known what the effect of what could be described as “subcatastrophic” injury at the time of resternotomy is. Also, given the fact that the literature on this matter is, to some extent, a bit outdated, it is important to know what the current rates of this complication are using strategies and protocols that have been adopted over the last 15 years.

This article attempted to look at all cardiac injuries, not just those that are catastrophic, that are from previous sternotomy. Unlike previous authors, we found that injury at the time of resternotomy in our group of patients was not associated with higher rates of morbidity or mortality.

In 1984, Dobell and Jain² sent a questionnaire to 131 surgeons about the performance of a second sternotomy

and assessed 144 severe hemorrhages that occurred. Eighty-eight percent of the hemorrhages occurred in situations in which the pericardium had not been closed at the first operation, providing the impetus for many surgeons to adopt this practice. They reported high mortality rates associated with injury, with a 56% mortality associated with coronary artery bypass injury, 47% with aortic injury, 39% with right ventricle injury, 25% with right atrial injury, and 13% with innominate vein injury. In our group, no one type of injury was statistically associated with a higher risk of mortality. But two of the four patients with an injury to the pulmonary artery died, which suggests that injury to the pulmonary artery may be more morbid than injury to other structures.

Follis and colleagues¹ reported a series of reoperations in 568 patients who had 610 reoperations over a 22-year period in 3 hospitals. They examined primarily “catastrophic hemorrhage” during resternotomy, defined as blood loss requiring transfusion. Their overall mortality rate for reoperation was almost identical to ours (50 of 610; 8.2%). Their injury rate was quite low, at 0.06% (4 of 610). Two of the 4 patients (50%) died in their injury group. We did look at catastrophic, or impending catastrophic hemorrhage. Bleeding in this subgroup required cessation of sternotomy, and the rate of urgent femoral bypass was 1.8% (11 of 612). None of the patients in this group died. These authors also sent a questionnaire to 4,200 members of the Society of Thoracic Surgeons. This questionnaire identified 1,557 injuries, with the majority being in the right ventricle (39%), mammary and vein grafts (32%), the aorta (15%), and the innominate vein (6%). Our data compared well with these numbers; 67% of our injuries were to grafts or the right ventricle compared with 71% in the Follis and associates’ questionnaire group. Their rate of only 0.06% injuries caused (4 in 22 years) is to be commended. Most likely, they did not count noncatastrophic injuries, although we counted all injuries.

Tembeck and coworkers⁴ published a series of 179 patients who underwent resternotomy over an 8-year period. After having 2 major hemorrhages in the first 66 patients, with 1 death, they adopted a protocol that involved preoperative CT scan, echocardiography, and partial femoral bypass for high-risk patients. Intraoperatively, they used an oscillating saw to divide the anterior table of the sternum and used scissors for the posterior table of the sternum. They had no major hemorrhage in the group of 113 patients who had the new protocol.

Garrett and Matthews⁸ published a series of 50 patients on whom they performed resternotomy by pulling up on the sternal wires and using an oscillating saw, with no incident. Akl and coauthors⁵ also reported a series of 50 pa-

tients with no complications using an oscillating saw technique. O'Brien and colleagues³ described a technique of direct vision resternotomy and graded the injuries that occurred in 546 resternotomies over a 21-year period. They had a 30-day mortality rate of 2.9% and had 9 minor heart lacerations and no moderate or major injuries.

We found that fourth-time sternotomy was an independent risk factor for cardiac injury. This is concordant with results from a study by Morishita and associates⁶ that looked at a series of 90 patients undergoing valve replacement, who had undergone 2 or 3 previous sternotomies. They also found, by multivariate analysis, that fourth-time sternotomy was an independent risk factor for sternotomy-related injury.

Our series of patients is a large, single institution series on this subject. We looked at not just catastrophic hemorrhage, but also the effects and risk factors of any inadvertent injury at the time of resternotomy. We found that fourth-time sternotomy is a risk factor for cardiac injury. But when injury does occur, it is not associated with any higher morbidity or mortality than are found in resternotomy patients who do not have an injury. The rate of injury is similar to that in other studies on this matter.

We suggest the following protocol, which we use at the University of Virginia. Any patient who had previous coronary artery bypass surgery should have a preoperative repeat catheterization. Lack of movement of coronary artery grafts on the catheterization films should raise the suspicion of a graft that is adherent to the sternum, so going into the operating room, the surgeon is not surprised. In addition, it is important to know if a patent graft is lying anteriorly. More than two previous sternotomies should prompt the surgeon to get a preoperative CT scan to evaluate the amount of space between the heart and any patent grafts, and the proximity of the great vessels. We would not object to the use of preoperative CT scans in all reoperations. Previous operative notes should be obtained for all patients. Finally, the surgeon should be sure that the pump team and the anesthesiologists are ready if there is a need to emergently go on bypass from the groin. We usually place a groin arterial line so that the Seldinger technique can be used to place groin cannulas for emergent bypass. Finally, the conduct of the first operation sets up the morbidity of the second.

In summary, we have found that injury at the time of resternotomy is not an entirely uncommon occurrence. But when it does occur, it does not have to mean any additional morbidity to the patient.

Author Contributions

Study conception and design: Ellman, Smith, Kron
Acquisition of data: Ellman, Smith, Girotti, Thompson, Peeler, Kern, Kron

Analysis and interpretation of data: Ellman, Smith, Kron
Drafting of manuscript: Ellman, Smith
Critical revision: Ellman, Kron

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Discussion

DR WILLIAM A BAUMGARTNER (Baltimore, MD): I first congratulate Dr Kron and his colleagues from UVA for a succinct and excellent presentation of a topic not really well described in cardiothoracic surgery literature. The authors report on 612 resternotomies, 8% of their practice, which across the country seems to be about the norm, over a ten-year period. Of this group, 9% had significant injury to a cardiac structure; most frequently, the bypass graft. However, of note, there is no difference in either mortality or morbidity in this group of patients compared to the group of patients who underwent resternotomy without injury. The only independent risk factor for injury was a fourth-time sternotomy. Additional placement of the patient on cardiopulmonary bypass did not have an effect on the injury pattern. These results are similar to the more contemporary articles that are referenced in the manuscript, contrasted to the 1984 paper by Dr De Belle and his colleagues, who reported a high mortality with severe hemorrhage on reopening the sternum.

The operative techniques described in the manuscript have reduced the incidence of catastrophic hemorrhage, particularly using a Stryker saw for the outer table and then dividing the inner table with the scissors. This has clearly decreased the injury pattern associated with reentry. Do you leave the wires in place when you divide the outer table? We have found them to be helpful to gauge the depth of the Stryker saw.

For the third sternotomy there were 26 patients who had a valve operation. How many of these patients had a previous coronary