Acute effects of suction retraction on atrial hemodynamics and histology

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Supported by a grant from Cardioventions.

Presented at the Owen H. Wangensteen Surgical Forum Program at the 89th Annual Clinical Congress Meeting of the American College of Surgeons, Chicago, Ill, Oct 22, 2003.

Received for publication June 16, 2004; revisions received Nov 11, 2004; accepted for publication Nov 23, 2004.

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J Thorac Cardiovasc Surg 2005;130:114-9
0022-5223/\$30.00

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doi:10.1016/j.jtcvs.2004.11.026

Objectives: In minimally invasive and robotic mitral valve surgery, a blade retractor is used to elevate the left atrial roof, which often distorts tissue and impairs visualization. We tested the hemodynamic and histologic changes of intra-atrial suction, using a new suction retractor that may improve stabilization and visualization.

Methods: Swine were divided into 3 equal ($n = 4$) groups: blade retractor, suction retractor, and arrested heart control. Left atrial ultrasonic crystals were used to record ejection fractions. After cardioplegic arrest, the atrium was opened and sampled for preretractor histology. Retractors remained in place for 1 hour, followed by postretractor histologic sampling. Controls were crossclamped for an equivalent time and postarrest histologic data obtained. Animals were weaned from bypass, data were collected for 4 hours, and postsacrifice atrial histologic samples were obtained.

Results: The main effect due to treatment was not statistically significant ($P = .52$) between the 3 groups, with the 4-hour average ejection fraction for blade retractor, suction retractor, and control being statistically equivalent at $33.3\% \pm 8.3$, $35.3\% \pm 12.1$, and $40.8\% \pm 9.9$ (mean $\pm$ standard deviation), respectively. Histology showed equivalent amounts of myocyte fragmentation, interstitial edema, eosinophilia, and wavy fibers between blade retraction and suction retraction, while the latter showed slightly increased amounts of hemorrhage.

Conclusions: Atrial endocardial suction retraction appears to be safe with no acute changes in the left atrial ejection fraction or significant acute histologic differences, compared to blade retraction. Furthermore, intra-atrial suction may be applicable to procedures other than minimally invasive and robotic mitral valve repair for providing improved stabilization.

The emergence of minimally invasive and robotic cardiac surgery has altered the perception of very complex operations by both surgeons and patients. As incisions become smaller, the hospital length of stay is decreasing, and patients are returning to normal activities sooner.¹ However, the advent of smaller access sites has necessitated the use of novel retraction devices to aid in exposure, particularly in minimally invasive mitral valve surgery. The roof of the left atrium

Figure 1. Currently used blade retractor to elevate the left atrial roof.

must be elevated to facilitate adequate exposure of the mitral valve's critical anatomic elements when the surgeon uses a right minithoracotomy approach.

We have used AESOP (Intuitive Surgical, Sunnyvale, Calif) to perform more than 350 minimally invasive mitral valve operations and da Vinci robotic system (Intuitive Surgical) to perform more than 150 robotic mitral valve repairs. In all cases, an intra-atrial retraction system was used (Cardioventions, Somerville, NJ). This system consists of a post, inserted through the chest wall, and a blade that elevates the left atrial roof superiorly (Figure 1). Gradually, the weight of the heart causes the atrium to slide on the retractor, distorting the tissue and impairing visualization. Readjusting the retractor unnecessarily adds additional crossclamp and cardiopulmonary bypass times, especially

when the console surgeon must rescrub to reposition the retractor.

Suction retraction has been used on the ventricular epicardium to aid in off-pump coronary artery bypass grafting surgery; however, there has been no documented use of intra-cardiac suction retraction.² Furthermore, no study to date has evaluated the effects of such suction on the endocardium. We developed a retractor with a trough placed on the superior surface of the blade (Figure 2). This trough is connected internally to the post that holds the retractor; the retractor can then be attached to suction to allow for a continuous vacuum column, which firmly secures the atrial roof to the retractor.

The left atrial ejection fraction contributes to left ventricular end-diastolic volume and increases cardiac output,

Figure 2. Left, Currently used blade retractor. Right, Experimental suction retractor.

with some reports quoting as much as 50% augmentation.^{3,4} Damaged atrial tissue from suction retraction could contribute to significant loss of left atrial ejection fraction, resulting in a lower cardiac output.⁵ To test for possible deleterious effects, we investigated for changes in left atrial ejection fraction and histology associated with suction retraction.

Methods

Young adult swine (45 kg) were used in accordance with the "Guide for the Care and Use of Laboratory Animals,"⁶ after we received approval from the Institutional Animal Care and Use Committee. All animals were anesthetized with isoflurane and nitrous oxide. A femoral arterial monitoring line and internal jugular venous access line were placed, followed by a median sternotomy for cardiac access. Two sonomicrometry crystal pairs (Sonometrics Corp, London, Ontario, Canada) were sewn on the left atrial long (anteroposterior) axis and the short (mediolateral) axis. Baseline measurements were then recorded with the use of SonoLAB data acquisition software (Sonometrics Corp). Using standard cannulation techniques, we placed the animals on cardiopulmonary bypass and cooled to 30°C. Cardiac arrest was achieved with cold blood cardioplegic solution delivered into the aortic root.

Arrested heart control animals ($n = 4$) had immediate postarrest histologic samples of the left atrium taken for analysis. Samples were obtained by incising the free wall of the left atrium, followed by closure with a 5-0 Prolene (Ethicon, Inc, Piscataway, NJ) suture. All tissue samples were purposefully kept small ($<0.7\text{cm}^2$) to limit any negative hemodynamic effects. Cross-clamp times were deliberately set for 90 minutes to duplicate standard crossclamp times for robotic mitral valve operations.¹ The conventional blade retractor group ($n = 4$) had atrial samples obtained for preretractor histology from the incised atriotomy, followed by insertion of the retractor through the open atrium to elevate the roof and expose the mitral valve. The suction retractor group ($n = 4$) had tissue samples acquired similar to the blade retractor group, but, instead of using the conventional blade retractor, a prototype suction retractor was used (Cardioventions). Suction was set at 200 mm Hg, the minimal amount of suction necessary to hold the atrial tissue and not lose adherence. Both blade and suction retractors were inserted approximately 10 minutes after tissue sampling and left in place for 1 hour.

Blade and suction retractor groups had poststudy sampling obtained from remote locations on the atriotomy, followed by atrial closure. Arrested heart control animals had samples obtained by reincising the atrium at remote locations, followed by purse-string closure. Tissue sampling and atrial closure approximated 20 minutes; therefore, preretractor sampling, retraction time, and post-retractor sampling/atrial closure coincided with a 90-minute cross-clamp time. After crossclamp release, a lidocaine bolus, 1 mg/kg, was given, and a continuous infusion at 1 mg/min was started. The animals were weaned from cardiopulmonary bypass, and sonomicrometer crystal data was obtained every 15 minutes for 4 hours. After 4 hours, the animals were sacrificed, and the entire left atrium was then sectioned for histologic analysis.

Data obtained from the sonographic crystal pairs were analyzed with the use of SonoView and CardioSoft analysis programs (Sonometrics Corp). Left atrial volume was estimated by using the ellipsoid

of revolution without regression constants model $[(SAX)^2(LAX)]$, where SAX equals the short axis length and LAX equals the long axis length. This formula has been validated in animal studies for left atrial volume by using resin cast versus water displacement.⁷ Left atrial volume curves were produced with corresponding left atrial ejection fractions for control and experimental animals.

All statistical analyses were carried out with the use of SPSS for Windows (SPSS 12.0, SPSS Inc, Chicago, Ill); the funding agency had no role in interpretation of data. Both descriptive and inferential statistical methods were employed. All testing was based on determining statistical significance at a 2-sided alpha level of .05. Ejection fraction was described by using measures of central tendency (mean and median) and dispersion (standard deviation and range). We used repeated measures of analysis of variance to analyze the change in ejection fraction over time and the difference between treatment groups. Left atrial ejection fraction was measured for 10-second cycles every 15 minutes for 4 hours. We computed the average ejection fraction over all 10-second measures within each of the sixteen 15-minute intervals during the 4-hour study period. The measures considered in the analysis were the baseline and each of the sixteen 15-minute averages.

Histologic data were analyzed and graded by an independent blinded pathologist. Samples were fixed in 10% formaldehyde for a minimum of 24 hours. All specimens were marked with ink to maintain orientation and sectioned at 2- to 3-mm intervals. Representative sections were processed in a standard fashion through paraffin embedding. Each specimen was sectioned at 4- μm intervals and stained with hematoxylin and eosin. The sections were reviewed under light microscopy. The atrial tissue from all 3 groups was evaluated for the presence of necrosis, neutrophils, myocyte fragmentation, vacuolization, hemorrhage, eosinophilia, and wavy fibers, which are all markers of myocardial damage.

Results

The interaction between time and treatment group was statistically significant ($P = .037$). Figure 3 shows how the pattern of variation in ejection fraction over time differed for the 3 groups. The control group showed a gradual decline in ejection fraction, while the blade and suction groups showed an initial sharp decline from baseline, with a tapering decline in ejection fraction thereafter. By approximately 2 hours and 45 minute after baseline, the average ejection fraction of the 3 groups was virtually the same and remained so for the duration of the observation period.

After bypass, the average left atrial ejection fraction over the 4-hour period for blade retractor, suction retractor, and arrested heart control was $33.3\% \pm 8.3\%$, $35.3\% \pm 12.1\%$, and $40.8\% \pm 9.9\%$ (mean $\pm$ standard deviation), respectively. The main effect due to treatment on the average ejection fraction over all time points (ie, 4-hour average) was not statistically significantly different ($P = .52$) between the 3 groups (Figure 4).

Histologic analysis analyzed possible ischemic or mechanical damage caused by cardiopulmonary bypass or intra-atrial retraction. Table 1 compares the 3 groups with respect to myocyte fragmentation, eosinophilic and wavy

Figure 3. Comparison of treatment arms.

fibers, and hemorrhage. Eosinophilic and wavy fibers seen adjacent to the atrial incision site in the blade and suction groups likely represented mechanical and early ischemic damage due to the atriotomy; however, no difference was detected between blade, suction, and control

necropsy samples with respect to the length of full-thickness changes measured from the incision site (1-way analysis of variance, $P = .37$). The extent of histologic changes beyond these full-thickness changes were also recorded in the necropsy group. A scale was developed to

Figure 4. Comparison of average left atrial ejection fraction after weaning from bypass.

TABLE 1. Comparison of histologic samples

After retractor				Necropsy			
	Frag	Eos/WF	Hem	Frag	% Eos/WF		
					Eos/WF	FT	BFT
Blade	None	30%-90%	1	Min	1.0-1.2cm	10%-30%	1.25
Suction	Min	30%-90%	1	Min	0.6-0.9cm	5%-20%	1.83
Control	None	20%-30%	0	Min	0.6-0.9cm	10%-20%	1

Frag, Fragmented myocytes; Eos/WF, eosinophilia/wavy fibers; FT, full-thickness depth; BFT, beyond full thickness; min, minimal; Hem, hemorrhage (scale: 0 = none, 1 = subendocardial, 2 = subendocardial and focal interstitial, 3 = diffuse).

document the degree of hemorrhage past these full-thickness changes. The scores for each cohort were averaged and are reflected in Table 1.

Discussion

Minimally invasive cardiac surgery necessitates the use of novel retraction devices. Traditional techniques for cardiac positioning and stabilization, such as epicardial suction, are expanding to include other applications. Numerous reports describe epicardial ventricular suction, specifically with respect to off-pump coronary artery surgery and cardiac stabilization.⁸ However, the majority of these reports examine stabilization techniques, patient hemodynamics, and clinical outcomes. To our knowledge, there has been no research on the feasibility or deleterious effects posed by intracardiac suction. In addition, there has been no published research on either epicardial or endocardial atrial suction.

Our study shows that arresting the heart decreases post-bypass left atrial ejection fraction. This finding is not surprising as prior studies have confirmed depression of cardiac output postbypass, even in previously healthy hearts. Royster⁹ comments that the ischemic insult of aortic cross-clamping, inadequate myocardial protection with cardioplegic solutions, hypothermia with cardioplegic and topical iced solutions, and reperfusion injury all contribute to myocardial injury and depressed left ventricular ejection fraction after cardiopulmonary bypass. Gray¹⁰ found a decline in left ventricular ejection fraction from an average of 58% preoperative to a nadir of 41% in the postbypass period, a 30% decrement in function. This finding is near our 40% decrease (from 56%-32%) in left atrial ejection fraction with our arrested heart control group, validating a depression in atrial function even without atriotomy or retraction. In addition, multiple studies in the postbypass patient have confirmed the nadir for ventricular function at 4 to 6 hours postbypass, with complete recovery occurring around 24 hours.⁹ Our study analyzes the acute 4-hour postbypass period. Studies of longer duration will be needed to completely demonstrate recovery and further characterize possible complications such as arrhythmias in the postoperative period.

Relatively little published data exist on histologic changes of the myocardium due to suction. Borst and colleagues² investigated the possible deleterious effects of epicardial left ventricular suction on the beating heart. They reported no difference in blood pressure or heart rate during suction immobilization. With respect to tissue damage from suction, they visualized hematomas at the suction site 2 days postoperatively, which resolved by 6 weeks. They sampled histology at 1 to 4 hours after suction and found capillary vasodilatation with myocardial tissue hemorrhage to a maximum depth of 2.5 mm. Histology at 6 weeks showed only a fuzzy transition between myocardium and epicardium.

We specifically investigated whether atrial suction retraction causes myocardial injury. Tissue samples from all 3 groups were examined for signs of irreversible myocardial injury, which include infarct necrosis, colliquative myocytolysis, and contraction band necrosis.¹¹ Infarct necrosis (coagulation necrosis with peripheral infiltration by neutrophils) and colliquative myocytolysis (vacuolization with myofiber loss) were not found in any of our histologic samples; however, there were areas that appeared consistent with contraction band necrosis. Contraction band necrosis is characterized by markedly eosinophilic myocytes with fragmentation and formation of a banding pattern seen on light microscopy.¹¹ This type of necrosis, which has been associated with both mechanical trauma and catecholamine administration,^{11,12} is generally associated with reperfusion injury that occurs after ischemia or continuous inadequate perfusion.¹² Contraction band necrosis has been well documented in patients surviving for short periods of time after cardiac surgery and can range from scattered foci to transmural areas.¹² While eosinophilic and wavy fibers were present in our tissue samples, contraction bands were not prominent. The significance of intact eosinophilic fibers is not known: They may represent reversible or irreversible injury.¹¹ Transmural areas of eosinophilic change were seen adjacent to the atrial incision site and were likely related to mechanical or ischemic injury due to the incision. Beyond these areas of full-thickness injury occurring near the atrial incision sites, varying areas of eosinophilia and wavy fibers predominated. Although both blade retraction and suction retraction had more findings of eosinophilia and wavy fibers over the control arm, no significant difference existed between blade retraction and suction retraction. In addition, we measured and graded the degree of hemorrhage in each sample, even though this has never been studied to be a predictor of myocardial injury. Suction retraction did have a slightly increased amount of hemorrhage over both blade retraction and control, but the significance of this finding is unclear as previous studies have shown complete resolution at 6 weeks.¹⁰ With respect to our acute findings, future studies must be lengthened to corroborate our results

since neutrophils associated with infarct necrosis, the first definitive marker of irreversible injury, begin to marginate at 6 to 8 hours after ischemic injury. These findings are subsequently apparent in necrotic tissue sections at 12 to 18 hours, thus necessitating a more lengthy study.^{11,12}

Conclusion

Intra-atrial suction retraction causes no detectable acute changes in left atrial ejection fraction or significant acute histologic changes, compared to conventionally used blade retractors. Potentially reversible histologic changes were found with both blade retraction and suction retraction, while minimal histologic findings of irreversible myocardial damage were found in all experimental groups. The suction retractor's ability to improve visualization and stability was not directly tested with this experiment; however, we believe that stability was enhanced during the testing. Three-dimensional stabilization experiments are now ongoing. Therefore, as technology progresses and novel surgical devices become applied clinically, it will be imperative to continue rigorous evaluation of new devices to challenge the accepted standard.

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