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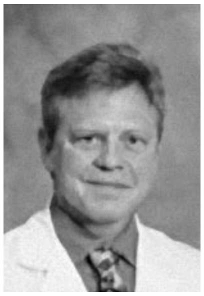
Evaluation of Hemodynamics: Comparison of Vacuum and Mechanical Stabilization in the Beating Heart



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ABSTRACT

Background: Hemodynamic instability remains a prominent concern for surgeons performing coronary surgery without cardiopulmonary bypass. The purpose of this study was to further elucidate the mechanism of hemodynamic instability by comparing vacuum stabilization to mechanical stabilization.

Methods: Four 60-kg swine were placed under general anesthesia. A median sternotomy incision was made, and baseline hemodynamic measurements were recorded. Mechanical and vacuum stabilization of the circumflex distribution were alternately compared with repeated baseline measurements in a counterbalanced method, and 32 experiments were conducted.

Results: There were significant differences between baseline hemodynamics and stabilized hemodynamics for mechanical stabilization versus vacuum stabilization, respectively, for the following parameters: blood pressure (mean decrement), –32.18% ($P = .0028$) versus –31.3% ($P = .0006$); cardiac output, –31.03% ($P = .0046$) versus –35.2% ($P = .03$); and mixed venous oxygen saturation, –29.8% ($P = .008$) versus –27.4% ($P = .0004$). There were no statistical differences between mechanical and vacuum stabilization when their decremental effects on baseline hemodynamics were compared with each other for any of the measured variables.

Conclusions: The mechanisms of hemodynamic compromise during coronary stabilization remain to be fully elucidated. Our study demonstrates no statistical difference between vacuum and mechanical stabilization on the measured hemodynamic values. More sophisticated studies involving detailed analysis of motion and geometry are required so that technical solutions to hemodynamic instability can be developed.

INTRODUCTION

Hemodynamic perturbations occur frequently during the performance of coronary bypass employing the off-pump coronary artery bypass (OPCAB) technique. These disturbances are particularly prominent during bypass procedures involving the circumflex coronary artery. Hemodynamic instability is the most commonly cited reason for the discontinuance of OPCAB bypass or for the avoidance of OPCAB surgery altogether (D.J.B., unpublished interviews with more than 100 surgeons and surgery personnel, 1997-2002; Guidant OPCAB preceptorship conducted in Indianapolis, IN, USA). A number of techniques have evolved to reduce or eliminate hemodynamic instability during the performance of OPCAB surgery [Shennib 1997, Jansen 1998, Mueller 2002], and they are broadly divided into anatomical and physiological techniques. The anatomical techniques include extensive division of the pericardial restraints to rolling the heart into the right pericardial recess. The pericardium is divided deep into the right chest down to a point just anterior to the phrenic nerve. The right chest wall is stretched upward to permit the heart to subluxate beneath the right sternal edge. Physiological techniques include volume loading and gravitational positioning to enhance hemodynamic stability. In addition, inotropic and anesthetic management are critical adjuncts to hemodynamic stability. The recent development of the apical suction devices Xpose (Guidant, Indianapolis, IN, USA) and Starfish (Medtronic, Minneapolis, MN, USA) have appeared to greatly facilitate access to all parts of the coronary anatomy with reduced hemodynamic impact.

Exposure of the coronary artery and its stabilization are two different problems. Although exposure of the coronary artery requires displacement of the heart, leading to hemodynamic compromise, stabilization contributes independently to decrements in cardiac output by creating an area of akinesis. Two techniques are currently available to stabilize the epicardial surface for off-pump coronary bypass. These techniques use vacuum stabilization (Axius 2, Guidant; Octopus, Medtronic) or mechanical stabilization (Guidant and others). The relative merits of these systems have been presented elsewhere [Jansen 1998, Burfeind 1998, Detter 2002]. To evaluate further the hemodynamic variables contributing to hemodynamic compromise, we conducted a study to compare vacuum stabilization with mechanical stabilization. This comparison focused on the circumflex coronary artery, because its exposure and stabilization produce the greatest hemodynamic challenge to any stabilizer system.

MATERIALS AND METHODS

Approval for this experiment was obtained from the animal care committee. All animals were euthanized at the

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Table 1. Comparison of the Hemodynamics of the Guidant Mechanical Stabilizer versus the Baseline*

	HR, beats/min	BP (Mean), mm Hg	CVP, mm Hg	PAD, mm Hg	PAWP, mm Hg	CO, L/min	SvO$_2$, % saturation	SVR, dyne·s·cm^{-5}
Baseline	71.125 ± 6.85	54.375 ± 5.43	5 ± 0.977	11.375 ± 3.10	7.5 ± 1.43	2.9 ± 0.73	75.5 ± 2.56	1566.14 ± 513.15
Stabilized	69.625 ± 7.02	36.875 ± 8.2	7 ± 1.17	9.875 ± 2.65	7.625 ± 1.11	2 ± 0.59	53 ± 8.82	1275.99 ± 347
Change (statistical significance)	NS	32.184% (*P* = .0028)	28.57% (*P* = .0219)	NS	NS	31.03% (*P* = .0046)	29.8% (*P* = .0008)	18.6% (*P* = .0365)

*Data are presented as the mean ± SD. HR indicates heart rate; BP, blood pressure; CVP, central venous pressure; PAD, pulmonary artery diastolic pressure; PAWP, pulmonary artery wedge pressure; CO, cardiac output; SvO$_2$, mixed venous oxygen saturation; SVR, systemic vascular resistance, where SVR = [(BP mean – CVP)/CO] × 80; NS, not significant.

conclusion of the experiments according to regulations governing the humane treatment of animals. Four euvolemic, 60-kg swine were placed under general anesthesia by an anesthesiologist extensively experienced in OPCAB surgery. Saline was administered to maintain euvolemia. No inotropes or vasoconstrictors were used to renormalize the hemodynamics. An arterial line, a continuous-output pulmonary artery catheter with mixed venous oxygen saturation (SvO$_2$) measurement (OptiQ; Abbott Laboratories, North Chicago, IL, USA), and a systemic oxygen saturation probe were placed. Electrocardiographic leads were placed to measure heart rate. A median sternotomy was performed in the standard fashion. The Guidant mechanical stabilizer and the Octopus 2 vacuum stabilizer were evaluated in a counterbalanced manner. Baseline measurements were recorded for 5 minutes to obtain average cardiac output, mean arterial blood pressure, pulmonary artery diastolic pressure, pulmonary artery wedge pressure, central venous pressure, heart rate, and SvO$_2$. The heart was then displaced with either the Xpose or the Starfish system. The Guidant mechanical stabilizer or the Octopus vacuum stabilizer was then placed in the distribution of the circumflex coronary artery for 5 minutes, and hemodynamic measurements of average cardiac output, mean arterial blood pressure, pulmonary artery diastolic pressure, pulmonary artery wedge pressure, central venous pressure, heart rate, and SvO$_2$ were repeated. Systemic vascular resistance was calculated by the following formula: systemic vascular resistance = [(mean blood pressure) – (central venous pressure)]/(cardiac output)] ± 80. Each stabilized measurement was followed by 5 minutes of rest and return to baseline, and the sequence was repeated with the alternate stabilizer system. This sequence was employed with each animal for a total of 4 cycles. A clinical determination of the adequacy of stabilization for the performance of an anastomosis was made for each experiment. Data were recorded on a spreadsheet, and the mean and SD were calculated. Analysis of variance and the Student *t* test were carried out to ascertain statistical significance of the differences between the control measurements (baseline) and the stabilized hemodynamic measurements.

RESULTS

Thirty-two sets of experimental data were recorded (16 baseline and 16 stabilized sets). There were highly significant differences between the baseline and the stabilized hemodynamic measurements for both the Guidant mechanical-Xpose and the Medtronic Octopus-Starfish systems (Tables 1 and 2).

Most notably, there were significant reductions in the mean blood pressure for both the Guidant and the Medtronic systems compared with the baselines (–32.18% [*P* = .0028] and –31.3% [*P* = .0006], respectively). Statistically significant differences in cardiac output and SvO$_2$ were also noted (Tables 1 and 2).

In contradistinction, there were no significant differences between the Guidant mechanical-Xpose system and the Medtronic Octopus-Starfish system with respect to hemodynamic effects during stabilization for any of the measured variables (Table 3).

DISCUSSION

Hemodynamic instability remains a major obstacle to the widespread adoption of OPCAB surgery. Many different stabilizers provide excellent platforms in which to perform

Table 2. Comparison of the Hemodynamics of the Medtronic Vacuum Stabilizer versus the Baseline*

	HR, beats/min	BP (Mean), mm Hg	CVP, mm Hg	PAD, mm Hg	PAWP, mm Hg	CO, L/min	SvO$_2$, % saturation	SVR, dyne·s·cm^{-5}
Baseline	73.875 ± 9.7	53.5 ± 3.76	4.875 ± 1.07	11.25 ± 2.45	8 ± 1.34	3.125 ± 1.07	75.625 ± 4.54	1590.9 ± 573.77
Stabilized	72 ± 8.0	36.75 ± 4.17	6.875 ± 0.94	9.5 ± 1.85	8.125 ± 2.08	2.0 ± 0.69	54.875 ± 7.6	1392.81 ± 382.42
Change (statistical significance)	NS	31.3% (*P* = .0006)	29.1% (*P* = .0052)	15.56% (*P* = .0127)	NS	35.2% (*P* = .0302)	27.4% (*P* = .0004)	NS

*Data are presented as the mean ± SD. Abbreviations are expanded in the footnote to Table 1.

Table 3. Comparison of Hemodynamics with the Guidant Mechanical System versus the Medtronic Vacuum System (Stabilized)*

	HR, beats/min	BP (Mean), mm Hg	CVP, mm Hg	PAD, mm Hg	PAWP, mm Hg	CO, L/min	SvO_2, % saturation	SVR, dyne·s·cm^{-5}
Stabilized Guidant mechanical	69.625 ± 7.02	36.875 ± 8.2	7.0 ± 1.17	9.875 ± 2.65	7.625 ± 1.11	2.0 ± 0.59	53 ± 8.82	1275.99 ± 347
Stabilized Medtronic vacuum	72.0 ± 8.0	36.75 ± 4.17	6.875 ± 0.94	9.5 ± 1.85	8.125 ± 2.08	2.0 ± 0.69	54.875 ± 7.6	1392.81 ± 382.42
Statistical significance	NS	NS	NS	NS	NS	NS	NS	NS

*Data are presented as the mean ± SD. Abbreviations are expanded in the footnote to Table 1.

coronary bypass surgery without cardiopulmonary bypass and with reasonable or excellent stabilization. Stabilization and exposure are obtained, particularly in the circumflex distribution, at the expense of normal hemodynamics. Exposure of the lateral coronary arteries via cardiac rotation principally affects the right ventricle and venous inflow. Stabilization affects biventricular performance [Mathison 2000].

Vacuum stabilization has been touted as less disruptive to hemodynamic stability. It has been surmised that vacuum stabilization produces less ventricular compression. This supposition is based on a pullback force being created by the vacuum, which reduces the amount of compression required to achieve adequate stabilization [Jansen 1998, Mueller 2002]. As our study indicates, the causality of hemodynamic compromise is more complex than compressive forces alone can account for, given the observed equivalence in the current study of the hemodynamic impact of mechanical and vacuum stabilization on all assessed hemodynamic parameters. Other mechanisms, therefore, must come into play.

Coronary stabilization by definition creates an area of akinesis. The amount of akinetic myocardium is dependent on many factors, some of which remain to be elucidated. Certainly, the footprint of the stabilizer is one factor. The larger the "sweet spot" is for performing an anastomosis, the greater will be the area of akinesis. The mere placement of a coronary stabilizer may produce myocardial ischemia in the surrounding myocardium or even global ischemia secondary to poor perfusion. Such ischemia is particularly plausible in the patient with multiple flow-restricting lesions.

The physical interaction between the stabilizer and the underlying myocardium is potentially 6-dimensional (the x, y, and z axes plus their respective velocity vectors). Even slight alterations in ventricular geometry or motion may lead to mitral regurgitation and further compromise the hemodynamics. Detailed studies of motion and the geometric interactions during stabilization, particularly in the z plane, are required to fully elucidate the causes of hemodynamic compromise. Discovering these causes will require the use of highly sensitive detectors to quantify motion in 3 dimensions. Imaging techniques employing transesophageal echocardiography with internal points of reference, eg, the anterior papillary muscle, do not possess sufficient resolution to provide the required data.

Much remains to be learned about cardiac exposure and stabilization. If OPCAB is to achieve its potential widespread application, then the factors that contribute to hemodynamic instability must be rigorously studied. Only then may technical solutions be devised that promote better hemodynamics.

ACKNOWLEDGMENTS

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REVIEW AND COMMENTARY

1. Editorial Board Member MB134 writes:

a) The OptiQ continuous cardiac output device does not report instantaneous data. The computer presents a digital readout of cardiac output, but the calculation is made based on a rolling 15-minute average of all data points. This means that for a 5-minute test period there are still 10 minutes of preexperiment data in the rolling average. This could create misleading cardiac output values during the reported test period of cardiac displacement. Please comment on the effect of this method of testing on your results.

b) Suction stabilizers are only supposed to reduce hemodynamic effects if the stabilizer is lifted away from the heart after application. If suction stabilizers are pressed down, they become mechanical stabilizers. Did the authors attempt to lift the suction stabilizers after application?

c) Data points were acquired sequentially on the same animal. For instance, the stabilizers were studied during 4 independent-but-serial lifting events. Is it possible that the final lift shows more hemodynamic compromise than the initial lift? Did the authors look at the initial data points and the final data points with their statistical analysis?

d) I think it would be best if the authors reported a control group for which 4 sequential lifts were done with the same stabilizer and the initial and final lifts were compared.

Authors' Response by Daniel Beckman, MD:

a) The OptiQ indeed does not report instantaneous data. It has 4 modes that differ in the way they average the data over time. The normal mode, which has the highest signal-to-noise ratio, begins to respond to changes in cardiac output within approximately 5 minutes. The urgent mode, which produces the least amount of noise artifact rejection, responds to changes in cardiac output in approximately 2 minutes. We used the urgent mode for better responsiveness. Because the animals served as their own controls, we were not so much interested in the absolute cardiac output as in the change in cardiac output. Every effort was made to keep the animal thermally quiet to reduce the noise.

b) Yes, we attempted to provide optimal stabilization with the vacuum stabilizer by using the attach-and-lift technique. Optimal stabilization was achieved by eyeballing the epicardial surface, a practice based on the first author's clinical experience. We are working on a device to better quantify motion in the x, y, and z planes and plan to repeat the experiment with particular emphasis on z-axis motion.

c) The data were collected in a counterbalanced fashion to eliminate interanimal variability. We anticipated hemodynamic deterioration as each experiment proceeded, but we did not see it. We cannot explain our experience except that assiduous attention was paid to anesthetic management by an experienced anesthesiologist (Dr. Bumb).

d) This is a very good suggestion; however, we felt that the counterbalance technique would better account for the variation in geometry between animals.