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Assessment of retrograde cardioplegia distribution using contrast echocardiography

Assessment of Retrograde Cardioplegia Distribution Using Contrast Echocardiography

Solomon Aronson, MD, Bryan K. Lee, MD, John R. Liddicoat, MD, Jeff G. Wiencek, BS, Stephen B. Feinstein, MD, John E. Ellis, MD, Michael F. Roizen, MD, and Robert B. Karp, MD

Section of Cardiac Surgery and Department of Anesthesia and Critical Care, University of Chicago, Pritzker School of Medicine, Chicago, Illinois

Retrograde cardioplegia has gained popularity in coronary and noncoronary cardiac operations. We have used contrast echocardiography in the open-chest canine model to compare the distribution of cardioplegia delivered antegrade in the aortic root versus retrograde through the coronary sinus, and to determine the effect of coronary occlusion on that delivery. With no coronary occlusion, antegrade cardioplegia was distributed to the entire left ventricle and septum whereas retrograde cardioplegia was distributed to the left ventricular free wall but had inconsistent delivery to the septum. Acute occlusion of the left circumflex coronary artery resulted in 57.06% ± 9.52% of the left ventricle not being perfused by antegrade cardioplegia and occlusion of both the left circumflex and anterior descending coronary arteries caused a 65.46% ± 18.5% reduction in perfusion by antegrade cardioplegia. Acute coronary occlusion had no effect on retrograde cardioplegia distribution. We conclude that retrograde cardioplegia is less homogeneous than antegrade cardioplegia in the intact coronary circulation but that retrograde cardioplegia preserves cardioplegia distal to acutely occluded coronary arteries. Furthermore, contrast echocardiography is a useful method of assessing myocardial perfusion and may have useful clinical applications.


30 mg/kg). The trachea of each dog was intubated; the lungs were ventilated by means of a Harvard respirator. The right femoral artery and vein were cannulated for systemic arterial blood pressure measurements and intravenous access, respectively. After median sternotomy, the azygous vein was ligated and a pericardial cradle was created. Venous cannulas were placed in the superior and inferior vena cavae. A 14F arterial cannula was placed in the left femoral artery. The dogs were given heparin (3 mg/kg) and cardiopulmonary bypass was initiated at 36°C and 2.2 L/min.

The ascending aorta was occluded, and cardioplegia solution was infused through an antegrade Y-type cardioplegia cannula placed in the proximal aortic root until the heart arrested in diastole. The right atrium was incised and a 10F Foley catheter was placed in the coronary sinus. A purse-string stitch was placed around the ostia of the coronary sinus to prevent back-bleeding around the cannula. The left anterior descending coronary artery was identified and isolated just distal to its first diagonal branch, and the left circumflex was isolated just proximal to its first marginal branch.

Ultrasound images of the short axis of the left ventricle at the level of the midpapillary muscle were obtained with a hand-held 3.5-MHz ultrasound transducer. Beginning 30 seconds before each contrast injection, ultrasound images were continuously recorded for 3 minutes on 1/4-inch VHS videotape to determine the distribution of cardioplegia injections. Cardioplegia line pressures were monitored to ensure that antegrade and retrograde pressures were within the respec-

1. Antegrade cardioplegia delivered through the coronary sinus.
2. Retrograde cardioplegia delivered through the coronary sinus.
3. Antegrade cardioplegia delivered through the coronary sinus.
4. Retrograde cardioplegia delivered through the coronary sinus.
5. Antegrade cardioplegia delivered through the coronary sinus.

The cross section of the midpapillary muscle was divided into four quadrants, and the areas of each quadrant were measured. The mean and percentage of each quadrant were calculated. The results were compared by Student's t test. All values are expressed as mean ± SD. A p value < .05 was considered statistically significant.
sures were maintained at 100 mm Hg and 50 mm Hg, respectively. The contrast agent was Albunex, produced by Molecular Biosystemix, Inc (San Diego, CA). Albunex sonicated albumin microbubbles are stable, nontoxic, and smaller than red blood cells. These microbubbles have known stable concentrations, shelf-lives, and diameters (mean particle size, 3.8 ± 1.0 μm with 98% less than 10 μm as verified by Coulter Counter and hemocytometry).

To minimize any reflux of contrast medium into the left ventricular cavity during antegrade delivery, cardioplegia was initially infused at high flow (5.8 mL/s) for a brief time (3 seconds) to snap shut the aortic valve leaflets. Cardioplegia was then stopped and 0.25 mL of Albunex sonicated albumin microbubbles were slowly loaded into the cardioplegia cannula through a three-way stopcock interposed between the cardioplegia line and the cardioplegia cannula. Cardioplegia infusion was then immediately resumed at 5.8 mL/s.

Retrograde infusion of cardioplegia through the coronary sinus cannula was reduced to 3 mL/s to maintain the cardioplegia line pressure at less than 50 mm Hg. Retrograde injection of Albunex microbubbles (0.25 mL) was similar to antegrade injection, except that the flow of cardioplegia was not interrupted to load contrast medium into the cardioplegia cannula through a three-way stopcock. After each intervention the aorta was unclamped, normal coronary flow was reestablished, and the heart resumed a sinus rhythm.

Cardioplegia was infused in the following manner during the following conditions:

1. Antegrade (through the aortic root cannula) with native coronary circulation intact.
2. Retrograde (through the coronary sinus cannula) with native coronary circulation intact.
3. Antegrade with the left circumflex branch (LCX) of the coronary artery occluded.
4. Retrograde with the LCX occluded.
5. Antegrade with the LCX and the left anterior descending artery occluded.
6. Retrograde with the LCX and left anterior descending artery occluded.

The cross-sectional image of the left ventricle at the midpapillary muscle level was arbitrarily divided into eight sections (Fig 1). Contrast medium was injected and the two-dimensional images were recorded on VHS tape. Representative images recorded at the height of contrast enhancement were then traced from the video screen onto x-ray film. All regions did not fill simultaneously. Therefore, only persistent defects were measured. The persistent presence or absence of contrast enhancement in the separate sections of the left ventricle (as described above) was graded by three separate, blinded observers and quantified with planimetry. The results of all observations were pooled for each injection and expressed as percentage of area not enhanced by contrast medium. Regions of filling defects after ACD and RCD were compared by Student’s t-test.

Results

Control

Control (no coronary occlusions) contrast injections resulted in the almost instantaneous enhancement of left ventricular muscle mass (Figs 2, 3). (The photographs shown are not always in the exact orientation schematically represented in Figure 1.) Antegrade cardioplegia delivery resulted in homogeneous echocardiographic enhancement with no filling defects (Table 1). Retrograde cardioplegia delivery was associated with less homogeneous enhancement and patchy filling defects that were isolated to the septum (Table 2).

Acute Coronary Occlusion

The visual effect of acute LCX ligation on antegrade contrast delivery is shown in Figure 2. Left circumflex artery occlusion resulted in 57% of the left ventricular cross-section studied not to be perfused by ACD. The location of the ACD filling defects created by left circumflex artery occlusion were most commonly located in the posterior and posterolateral regions of the left ventricular free wall (Fig 4). Left circumflex artery occlusion had no effect on RCD distribution (see Table 1). The effect of simultaneous occlusion of the LAD and left circumflex coronary arteries is shown in Figure 3. There was a 65% reduction in perfusion by ACD, most persistent in the anterolateral, posterolateral, posterior, and inferior regions of the free wall, whereas RCD was no different than control (see Table 1). The locations of the filling defects during ACD with circumflex and LAD occluded are shown in Table 2 and in Figure 5.

Comment

Retrograde cardioplegia delivery has been studied in the open-chest canine model using techniques to assess both
its distribution and its efficacy in providing myocardial protection. Shiki and associates [6] injected corrosion casts into the coronary sinus and showed retrograde delivery to the left ventricular free wall but inconsistent delivery to the interventricular septum. Striling and coworkers [3] demonstrated less efficient tracking of microspheres in the right ventricle and posteroseptal region of the left ventricle when microspheres were injected through the coronary sinus versus the aortic root. Acute coronary occlusion causes inadequate ACD to the myocardium subserved by the occluded artery. Retrograde cardioplegia delivery has been shown to provide superior cardioplegia delivery to this ischemic myocardium as assessed by myocardial cooling and microsphere delivery [7]. Furthermore, this improved cardioplegia delivery distal to an acutely occluded artery has been shown to result in improved functional and biochemical recovery [7-9].

The clinical use of RCD has gained in popularity. Its efficacy of protection has been documented in coronary and noncoronary cardiac operations [1, 2, 10]. Problems with right ventricular and septal protection have not become apparent and may represent anatomical differences in human versus canine hearts.

The present study uses contrast echocardiography to provide a direct visual image of antegrade and retrograde cardioplegia delivery and the effect of acute coronary occlusion on this delivery. Our findings include the following:

1. ACD results in homogeneous distribution of cardioplegia to the entire left ventricle in hearts with patent coronary arteries.
2. Acute coronary occlusion almost stops ACD to the myocardium distal to the occlusion.

Table 1. Comparison of Antegrade and Retrograde Cardioplegia: Percent Filling Defect

<table>
<thead>
<tr>
<th>Condition</th>
<th>Antegrade (%)</th>
<th>Retrograde (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.0 ± 0.0</td>
<td>12.38 ± 6.4</td>
</tr>
<tr>
<td>LCX occluded</td>
<td>57.06 ± 9.52*</td>
<td>13.06 ± 14.6*</td>
</tr>
<tr>
<td>LCX and LAD occluded</td>
<td>65.46 ± 18.50*</td>
<td>13.40 ± 1.72*</td>
</tr>
</tbody>
</table>

* Significant when compared with control (antegrade), p < 0.01. # Significant difference between experimental conditions and control (antegrade).

LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery.

3. RCD results in left ventricular

These findings provide a rationale for RCD to the left coronary artery but the present study does not cover the other branches.

Table 2. Location of Delivery/Intervention

<table>
<thead>
<tr>
<th>Delivery/Intervention</th>
<th>Retrograde/no occlusion</th>
<th>Antegrade/LCX occlusion</th>
<th>Antegrade/LCX/LAD occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = anterior; A = anterior; MS</td>
<td></td>
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</tbody>
</table>

* Mean ± standard deviation
3. RCD results in distribution of cardioplegia to the left ventricular free wall but not to the entire septum.

4. Acute coronary occlusion has no effect on RCD distribution.

These findings suggest that RCD in the setting of acute coronary occlusion may provide superior protection to the left ventricular free wall being perfused by the coronary artery but that ACD in the intact coronary circulation provides more homogeneous and complete distribution. It should not be assumed that acute coronary occlusion in the otherwise normal canine heart reflects what is seen clinically in humans. Coronary atherosclerosis is a gradual process allowing for the development of collateral circulation in the noninfarcting, nonischemic heart. Even with complete coronary occlusion or severe, multiple stenoses, there must be adequate blood supply to provide baseline oxygen requirements. One might expect that in this setting ACD could follow the same route and provide protection. There is clinical evidence, however, that this does not always occur and that ACD may be inadequate even without ongoing ischemia or infarction [11]. The mechanism by which this occurs is not known but may be secondary to loss of autoregulation during cardioplegia.

Table 2. Location of Filling Defects During Cardioplegia Delivery: Percent of Region Not Perfused

<table>
<thead>
<tr>
<th>Delivery/Intervention</th>
<th>IS</th>
<th>MS</th>
<th>AS</th>
<th>A</th>
<th>AL</th>
<th>PL</th>
<th>P</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrate/no coronary occlusion</td>
<td>39 ± 9</td>
<td>81 ± 4</td>
<td>40 ± 34</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Integrate/LCX occlusion</td>
<td>32 ± 3</td>
<td>24 ± 35</td>
<td>24 ± 33</td>
<td>41 ± 32</td>
<td>66 ± 42</td>
<td>98 ± 4</td>
<td>92 ± 16</td>
<td>60 ± 49</td>
</tr>
<tr>
<td>Integrate/LCX and LAD occlusion</td>
<td>44 ± 32</td>
<td>28 ± 37</td>
<td>39 ± 44</td>
<td>49 ± 43</td>
<td>78 ± 39</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
</tbody>
</table>

*Mean ± standard deviation. The numbers represent the percentage of cross-sectional area in the region specified not perfused by cardioplegia.

I = inferior; AL = anterolateral; A5 = anteroseptal; IS = intersseptal; LAD = left anterior descending; LCX = left circumflex; MS = midseptum; P = posterior; PL = posterolateral.
delivery and shunting of cardioplaegia away from potentially ischemic zones. The nonphysiologic delivery of cardioplaegia through the coronary sinus seems to be unaffected by obstruction, either acute or chronic.

The echocardiographic appearance of contrast medium injected antegrade versus retrograde is markedly different. Whereas antegrade injection results in a quicker homogeneous flush, retrograde injection appears more heterogeneous with streaming across the myocardial wall into the ventricular cavity through thebesian drainage. Retrograde cardioplaegia delivery may impart its protection by being an efficient way of applying "topical" hypothermia.

Contrast echocardiography is a useful method of assessing the presence or absence of regional perfusion. We and others have begun using this method in the operating room to assess cardioplaegia delivery and myocardial perfusion [12, 13]. In addition, we hope to ultimately gain insight into the fundamental question of what effect an arterial stenosis or occlusion has on distal perfusion and how a bypass graft affects that perfusion.

References