Apical suction leads to severe ischemia of the ventricular apex

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Abstract

Objective: Apical suction devices allow displacement of the heart in off-pump coronary artery surgery. However, high vacuum pressure may injure the suctioned myocardium. It has been demonstrated that partial pressure of oxygen in the myocardium (ptiO2) is a sensitive and rapid indicator of myocardial ischemia. The purpose of this study is to evaluate the effect of apical suction on the ptiO2 as an indirect measure of myocardial perfusion of the ventricular apex. Methods: Twenty-six patients undergoing elective off-pump coronary surgery were studied. Intramyocardial ptiO2 was continuously measured using a flexible catheter microprobe (Licox® GMS mbH, Kiel, Germany). Patients were divided into two groups. In one group (Group A; n = 12), the probe was inserted in the anterior wall of the left ventricle. Intramyocardial ptiO2 monitoring was made with the heart in the resting position and after placing the apical suction device. Results: In Group A, basal ptiO2 was 15.3 ± 7.4 mmHg. One minute after placing the apical suction device, the ptiO2 significantly decreased to 2.3 ± 1 mmHg (p < 0.001). A progressive increase of ptiO2 was observed immediately after the XposeTM suction device was removed. ptiO2 was 13.6 ± 9.1 mmHg 5 min after releasing the suction cup and increased to 27.2 ± 12.6 mmHg 20 min later. In Group B, basal ptiO2 was 17 ± 10.3 mmHg. No significant changes were observed in Group B after placing and removing the suction cup. Conclusions: Apical suction devices lead to severe ischemia of the suctioned myocardium. Collapse of coronary vessels due to vacuum pressure is a possible mechanism. Reperfusion occurs immediately after removing the suction cup and a significant reactive hyperemia is observed.

Keywords: Off-pump coronary surgery; Tissue oxygen; Vacuum heart positioner

1. Introduction

Coronary artery revascularization without the use of cardiopulmonary bypass (OPCAB) has emerged as an alternative to conventional coronary artery bypass grafting. Displacement of the beating heart for target exposure has been found to cause various degrees of hemodynamic disturbance and this is still an important factor limiting the performance of OPCAB. Numerous positioning techniques and devices have been developed to facilitate the exposure of lateral and posterolateral coronary vessels [1,2].

Apical suction devices allow displacement and lifting of the heart while minimizing hemodynamic instability. By pulling out and upward, these devices prevent the distortion of the ventricles and mitral annulus maintaining the normal heart geometry, especially the long-axis dimensions [3].

Subepicardial hematoma formation over the heart apex is common after applied suction pressure. This apical hematoma does not usually cause disturbances and vanishes at the end of the procedure. There are no clinical data about how myocardial perfusion of the apex may change during the use of apical suction devices. Although the application of vacuum pressure will not cause any sort of permanent myocardial damage, the apical device may temporarily compress the coronary vessels and consequently reduce the blood flow [2]. Direct compression of the left anterior descending coronary artery (LAD) by apical suction cup, which produced ischemia and hemodynamic compromise has been reported, and therefore, it is recommended that this device should not be engaged over a visible major epicardial artery [4].

The objective of this study is to evaluate the effect of apical suction on the partial pressure of oxygen in the
myocardium (ptiO2) using a polarographic modified Clark-type microelectrode as an indirect measure of myocardial perfusion of the ventricular apex [4–6].

2. Materials and methods

Twenty-six patients who underwent elective OPCAB for at least the LAD and an obtuse marginal branch of the circumflex artery were studied in a prospective manner. Informed written consent was obtained from all patients. Patients were divided into two groups. In one group (Group A; n = 14), the ptiO2 microprobe was inserted into the left ventricular apex. In the other group (Group B; n = 12), the microprobe was inserted into the anterior wall of the left ventricle. The ptiO2 microprobes are electrodes made of soft polyethylene. At the tip of the probe in a cylindrical cell containing an electrolyte solution, which is located concentrically along the axis of the microcatheter, there is a polarographic sensor. The oxygen diffuses through the tissue through the polyethylene wall of the catheter tube, into its inner electrolyte chamber. Here, the oxygen is reduced and the current flows proportionally to the pressure of oxygen in the tissue surrounding the catheter tip.

We investigated the effect of the XposeTM vacuum-assisted apical positioning device (Guidant, Santa Clara, CA, USA) on ptiO2 at the ventricular myocardium during the exposure of the circumflex artery branches. The XposeTM device consists of a compliant suction cup that is placed at the ventricular apex, which conforms to the heart and is designed to maintain secure contact with the epicardial surface at a low vacuum setting. Once suction is applied a tight seal is attained and the tip of the heart can be gently elevated while different positions of the arm allow for exposure of circumflex branches.

The anesthetic technique was standardized for all patients, which were monitored with systemic, pulmonary and central venous pressures, continuous cardiac output and mixed venous saturation of oxygen, pulse oximetry, ECG leads II and V5. Transesophageal echocardiography was done in five patients of Group A and four patients of Group B.

Operations were performed through a median sternotomy incision. The left internal thoracic artery and the left radial artery were harvested in all patients. Immediately after the pericardium was opened, a revoxode oxygen catheter-microprobe (Licox®, GMS mbH, Kiel, Germany) was inserted into the myocardium approximately 10 mm below the surface of the epicardium. The thermocouple temperature catheter-microprobe (Licox®, GMS mbH) was placed in the pericardial sac.

The polarographic sensor and the temperature probe were connected to a computer-controlled device (Licox CMP® GMS mbH). The data were taken every 2 s and immediately showed in the monitor of the device.

Vascular control of the coronary vessels was achieved with extraluminal snaring using silicon vascular loops. No intracoronary shunts were used. In all patients the LAD was revascularized first. Stabilization of the LAD was obtained using the Axius™ epicardial suction tissue stabilizer (Guidant).

To facilitate the exposure of the marginal branch, a Xpose™ apical suction device was applied on the apex of the heart. In Group A, the oxygen sensitive part of the probe was included into the dome, whereas in Group B the microprobe was at least 2 cm moved away from the cup. Vacuum pressure was applied and the heart was gently elevated and rotated counter-clock to expose the obtuse marginal branch. After completing the obtuse marginal anastomosis, the heart was released from the suction cup and fell back into the pericardial cradle freely beating.

Hemodynamic, electrocardiographic, and ptiO2 data were recorded every 2 min (1) 10 min after the insertion of the ptiO2 micro-catheter, (2) during the LAD anastomosis, (3) before application of the Xpose™, (4) during apical suction and circumflex grafting, and (5) up to 60 min after the cup was removed and the heart repositioned in its anatomical position.

One-way repeated measures analysis of variance was used to assess the significance of differences at each time interval within the groups and between the two groups. All results were expressed as mean ± standard deviation. A value of p < 0.05 was considered statistically significant.

3. Results

Demographic data are shown in Table 1. No significant differences were observed between the two groups. During the LAD anastomosis only a significant increase of the central venous pressure compared with basal values was observed in both groups. Exposure of the circumflex artery branches was achieved with the Xpose™ device. Vacuum pressure was set between –200 and –250 mmHg in both groups and maintained during a period of 15 ± 4 min in Group A and 16 ± 6 min in Group B. This period was accompanied by a significant increase of central venous pressure, mean pulmonary artery pressure and a decrease of cardiac output, and mixed venous oxygen saturation compared with basal values in both groups. After releasing the suction cup and returning the heart to its anatomical position, all parameters returned to normal values excluding the heart rate, which increased significantly in both groups. Hemodynamic parameters are shown in Table 2.

During the time in which the heart was lifted upward by the suction cup, an atypical ECG waveform was observed, probably due to the displacement of the heart from its anatomical position and the subsequent abnormal transmis-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Demographic and preoperative characteristics of the patients</th>
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<tbody>
<tr>
<td></td>
<td>Group A</td>
</tr>
<tr>
<td>Age (years)</td>
<td>68.2 ± 7.5</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>12/2</td>
</tr>
<tr>
<td>Risk factors</td>
<td></td>
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<tr>
<td>Diabetes</td>
<td>8 (57.1%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>7 (50%)</td>
</tr>
<tr>
<td>Smoking</td>
<td>5 (35.7%)</td>
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<tr>
<td>Hypercholesterolemia</td>
<td>9 (64.28%)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
</tr>
<tr>
<td>2-vessel disease</td>
<td>4 (28.5%)</td>
</tr>
<tr>
<td>3-vessel disease</td>
<td>6 (42.8%)</td>
</tr>
<tr>
<td>Left main</td>
<td>4 (28.5%)</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>55.2 ± 10.1</td>
</tr>
</tbody>
</table>

LVEF: left ventricular ejection fraction.
sion of cardiac electrical activity to the surface electrodes. After removing the Xpose™ and repositioning the heart in the pericardial sac, the ECG showed in seven patients of Group A and five patients of Group B, a significant transient ST segment elevation on lead V₅ which spontaneously resolved shortly after removing the suction cup (Table 3).

Changes of ptiO₂ in the myocardium of the left ventricle in Groups A and B during the surgical procedure are shown in Fig. 1. In Group A, mean ptiO₂ before application of vacuum pressure was 15.3 ± 7.4 mmHg. One minute after placing the Xpose™ device, the ptiO₂ significantly decreased to 2.3 ± 1 mmHg (p < 0.001) and reached near-zero after 5 min. The ptiO₂ started increasing immediately after removing the Xpose™. Twenty minutes after removing the cup, the ptiO₂ reached a maximal value of 27.2 ± 12.6 mmHg (p < 0.01) which was significantly higher than the basal. One hour after removing the Xpose™, no differences could be observed when compared with preoperative values. In Group B, basal ptiO₂ was 16 ± 6 mmHg. No significant changes of ptiO₂ were observed during the procedure. In both groups, a trend to a reduction of ptiO₂ during LAD snaring was observed but no significant differences could be demonstrated.

An epicardial hematoma was observed on the ventricular apex after releasing the Xpose™ positioner device in all the patients of both groups. Transient apical diskinesia (<5 min) of the ventricular apex could be observed on transesophageal echocardiogram in four patients of Group A and three patients of Group B.

All the patients were extubated less than 8 h after the procedure. No signs of perioperative myocardial infarction were observed except a slight increase of troponin I in all patients (<6 ng/ml) without significant differences between Groups A and B. Three patients of Group A and one patient of Group B developed postoperative atrial fibrillation between the second and sixth postoperative days and were successfully resolved with medical treatment.

4. Discussion

Animal and human studies have shown impairment of ventricular function during displacement in OPCAB due to cardiac chamber deformation. During lateral and vertical displacements, the heart buckles resulting in compression of the right ventricle, biventricular geometric abnormalities and mitral annulus deformation leading to hemodynamic instability [7,8].

Apical suction technology used for positioning the beating heart affords vertical displacement with minimal hemodynamic compromise. This is achieved by maintaining its overall geometry thus providing better exposure and hemodynamics than the deep pericardial suture technique [3,9,10].

It has been suggested that it is the relatively small volume of myocardium of the less dynamic thicker apex, which is immobilized by the suction device, and the unimpaired rotation along the long axis during the cardiac cycle that...
explains the minimal reduction of cardiac function when using the Xpose™ apical suction device [3, 9].

Experimental studies have demonstrated only a very slight myocardial injury with a model of epicardial suction device [11]. However, the amount of myocardial tissue under suction by this device is much less than the volume of myocardium subjected to negative pressure by Xpose™ apical device.

Although subepicardial hematoma is common after releasing the suction device, no clinical studies have been published concerning the histologic and metabolic effect of vacuum pressure applied to the human heart. However, it is conceivable that the application of the suction cup on the myocardial tissue may subject the underlying myocardium and small non-epicardial coronary vessels to stress on retraction, thus somehow limiting flow in the microvasculature. The negative pressure, which the myocardial tissue is subjected to within the suction cup may cause retraction, distortion, and collapse of all vessels within this segment, thus leading to myocardial ischemia.

It has been demonstrated that the application of negative pressure on the heart using suction stabilizers may cause mechanical compression of the myocardium and subsequent increase in regional vascular resistance suggesting a possible compromise of perfusion [12]. Isolated reports have demonstrated that suction pressure may injure deeper portions of the epicardium, producing significant hematoma spreading to the myocardium and producing bleeding and epicardial rupture [13].

Previous clinical reports have demonstrated that direct on line monitoring of ptiO2 using polarographic electrodes is an accurate and reliable indicator of myocardial oxygenation and allows safe use in routine clinical setting [14, 15]. The ptiO2 corresponds to the availability of oxygen at the cellular level and depends on the balance between oxygen supply and consumption and therefore is a sensitive and rapid indicator of myocardial ischemia and reperfusion.

Using ptiO2 monitoring, our study has demonstrated that the application of −200 to −250 mmHg of vacuum pressure onto the ventricular apex leads in all the patients to a rapid and significant decrease of ptiO2 in the apex suggesting that a complete collapse of all vessels and myocardial ischemia is produced immediately after negative pressure is applied. This decrease of ptiO2 is not observed in the anterior wall of the left ventricle. The trend in the decrease of ptiO2 in both groups during LAD grafting is probably related to a reduction of blood supply due to the arterial snaring, which may be partially compensated by the collateral circulation.

The ptiO2 observed in the apex after 5 min of suction on the beating heart is lower than in patients with global myocardial ischemia due to aortic cross-clamping. The massive collapse of the microvasculature due to the negative pressure may extract all the blood and oxygen in the interstitial fluid, whereas in the cardioplegic arrested flaccid heart, which maintains collateral circulation through the mediastinum, the decrease of ptiO2 is less severe [15].

The extent of coronary vessel compression by any vacuum device depends on the value of negative pressure and the design of the suction device. The Xpose™ draws the whole apex of the heart into the conical dome, which accounts for a volume of suctioned myocardium of approximately 15 ml. This high volume increases not only the amount of traction one can obtain but also the possible volume of ischemic myocardium. The Starfish™ multi-appendage suction device (Medtronic, Minneapolis, MN, USA) utilizes pressures of approximately −400 mmHg, whereas the Xpose utilizes pressures of −200 mmHg. However, there is considerably less tissue under vacuum with the Starfish™ device.

The ptiO2 increases in the apex immediately after releasing the suction cup which may be due to the opening of microvasculature of the apex when negative pressure is stopped. This rise in ptiO2 reflects reactive hyperemia and is a rebound, which has been previously reported in clinical and experimental models using polarographic electrodes [15, 16].

The transient ST segment elevation observed on lead V3 once the heart was returned to its anatomical position after releasing the Xpose™, and the reversible apical diskinesia may be related to a possible transmural ischemia produced by the apical suction. Recent demonstration of apical magnetic resonance imaging hyperenhancement after OPCAB and troponin I release without new Q waves may be explained by the suction-induced ischemia [17]. We believe that the transient ST elevation, apical diskinesia, and increased troponin I observed in our patients are due, at least in part, to the vacuum-induced ischemia. However, the period of suction is short, and therefore, no permanent ECG and echocardiographic changes are demonstrated suggesting that these devices may be safely used. It has been demonstrated that OPCAB has a smaller degree of surgically induced myocardial cell injury compared to conventional revascularization, but our study suggests that vacuum pressure may play a role in perioperative cardiac injury and, therefore, the period of suction must be as short as possible.

References


Appendix A. Conference discussion

Mr D. Taggart (Oxford, United Kingdom): I enjoyed your presentation very much and you have explained something that we observed in a previous study but didn’t quite figure out. We published a randomized trial of on-pump and off-pump CABG, in Circulation last year and using cardiac MRI reported an excess of small apical infarcts in the off-pump group, equivalent to about 2 g using cardiac MRI of tissue, so tiny amounts. But cardiac MRI is so exquisitely sensitive we could see these. We weren’t sure of the mechanism of it, but I am pretty sure this is it. So thank you for enlightening me.

Dr Y. Kassif (Ramat Gan, Israel): How do you prevent the bleeding on the LAD once you are going to do the anastomosis? And the reason I ask, of course, is whether you use a shunt or if you just occlude the LAD and maybe this will contribute to the ischemia that was measured and maybe the main reason for ischemia is not only the suction device but occlusion of the LAD.

Dr Fernández: We do not use an intracoronary shunt. We insert the microprobe in the left ventricular apex and we do not observe any significant decrease of the ptiO2 during the cross-clamping of the LAD. When we apply suction on the ventricular apex, the suction cup is placed far away from the LAD. There are several case reports describing occlusion of the LAD with the suction cup and therefore we avoid to apply the suction cup close to the LAD. The mechanism of reduction of ptiO2 is probably the collapse of the microvasculature of the left ventricular apex.

Dr P. Sielicki (Szczecin, Poland): According to your study, did you change your OPCAB policy?

Dr Fernández: No. According to our study, after releasing the suction cup, 50% of patients presented a transient ST segment elevation on the ECG monitoring on lead V5, which we have attributed to transmural ischemia of the left ventricular apex after more than 15 min of suction. And the other thing is, as Professor Taggart has told us, that we have observed always a discrete increase of troponin I in the postoperative period without any signs of myocardial infarction, and perhaps this increase of cardiac enzymes is due to the suction. We have not changed our policy, but when we observe an increase of troponin I, we attribute this finding to the suction cup.

Dr J. Gummert (Leipzig, Germany): I was going to actually ask the same question, whether you have changed your policy. We have had the experience that the suction cup is not really necessary for hemodynamic performance. So my question would be, when do you use the suction cup, in what patients, and do you use it in general or are there only special situations when you are using it?

Dr Fernández: We use the suction cup only for exposing the branches of the circumflex artery. In these 14 patients we do not put the suction cup when grafting the LAD. I think the hemodynamics are much more preserved with the suction cup than with the deep pericardial stay sutures. I think the suction cup is a good advantage but with some limitations.

Dr J. Bachet (Paris, France): Well, when we see all those drawbacks and difficulties coming up with off-pump bypass, perhaps we should use extracorporeal circulation. It could make things simpler and safer, right? Just a nasty comment.