Abstract

Many studies have shown important changes in lung function tests after coronary artery surgeries. It is controversial if off-pump surgery can give a better and shorter recovery than the on-pump. A prospective study was conducted on 42 patients submitted to coronary artery surgery and divided into two groups: 21 off-pump using intraluminal shunt (G1) and 21 on-pump (G2), matched by the anatomical location of the coronary arteries lesions. All patients had spirometric evaluation, blood gas measurements and alveolo-arterial oxygen gradient (A-aDo2), at the fourth and 10th postoperative days (PO and PO). Preoperatively, G1 and G2 had similar results (P > 0.372). Spirometry showed decreases at PO and remained decreased until PO in both groups, with significant differences between the groups. The blood gas measurements showed reduction in arterial oxygen pressure (PaO2) and carbon dioxide pressure (PaCO2), while there was an increase in A-aDo2 at PO and PO in both groups. The results suggest that different changes occur in pulmonary function when the surgery is performed with or without cardiopulmonary bypass. The off-pump patients showed significantly greater improvement than the on-pump group.

Keywords: Pulmonary function tests; Myocardial revascularization; Coronary artery bypass surgery

1. Introduction

Surgeries for coronary artery revascularization with cardiopulmonary bypass (CPB) as standardized in the 1970s and surgeries without CPB first reported by Ankeney [1], followed by others, are currently being performed in similar numbers. With the growing interest in minimally-invasive techniques, there has been an increase in revascularization without CPB. In 1984, Rivetti and Gandra [2] started to perform revascularization without CPB with the aid of a temporary intraluminal coronary device (shunt) in order to maintain blood flow in the artery, avoiding ischemia. Patients’ behavior submitted to this technique has been found to involve better postoperative clinical recovery, and their pulmonary function has started to be studied [3], as an extension of that experience.

Concern about pulmonary function after heart surgery started in the 1950s and 1960s [4] with the advent of CPB. Surgeries for coronary artery revascularization with CPB through sternotomy, and pulmonary function have been extensively studied by several investigators and have been found to be quite compromised [5].

Several factors have been analyzed as the causes of pulmonary changes after surgery for coronary artery revascularization with CPB, but few data are available about pulmonary function after revascularization surgeries without CPB. Buffolo et al. [6] reported pulmonary complications in 3.2% of patients without CPB and in 9.7% of patients with CPB, but no pulmonary function tests were applied to these patients. Later, at the same institution, Guizilini et al. [7] evaluated and compared the pulmonary function in patients following on- and off-pump coronary artery bypass grafting. Recently some authors have investigated how off-pump coronary artery bypass grafting affects postoperative pulmonary function.

Thus, the objective of the present prospective study was to compare pulmonary function between two groups of patients submitted to coronary artery revascularization, one without CPB, using the intraluminal temporary shunt and the other with CPB. All patients were operated in the same hospital. Both groups were submitted to the same postoperative care protocol and pulmonary function tests.

2. Methods

Forty-two patients were submitted to coronary artery revascularization by median longitudinal sternotomy and matched by the anatomical location of the coronary arteries lesions into two groups: G1 consisted of 21 off-pump patients (13 men and eight women), with the use of an intracoronary shunt, and G2 consisted of 21 on-pump patients (14 men and seven women). The criteria of selection was: both groups included patients with lesions in the anterior interventricular branch, the right coronary artery and the diagonal artery, while patients with lesions in the circumflex artery were only included in G1.
Age ranged from 35 to 75 years (mean: 58.8 ± 11.6 years) for G, and from 36 to 70 years (mean: 52.8 ± 9.4 years) for Gii. Height ranged from 139 to 178 cm in G (mean: 159 ± 11 cm) and from 142 to 175 cm in Gii (mean: 163 ± 9 cm). Weight ranged from 48 to 95 kg in G (mean: 70.4 ± 13.0 kg) and from 46 to 105 kg in Gii (mean: 73.8 ± 12.8 kg). Seventeen patients in G (81%) and 13 in Gii (62%) were smokers. Associated diseases were systemic arterial hypertension in G (86%) and Gii (76%), and diabetes mellitus in G (19%) and Gii (24%). According to the diagnosis of coronary artery disease, the patients were classified as having: stable angina, unstable angina and postinfarction angina in G (24%; 5%; 71%) and Gii (29%; 19%; 52%), respectively.

In G and Gii, the internal thoracic artery and the magna saphenous vein were used as a graft.

In Gii, a Sarns membrane oxygenator, anterograde blood cardioplegia and retroplegia through the coronary venous sinus were used. The priming volume for the CPB circuits was 1500 ml. Topical cooling of the heart during cardiac arrest was not used. CPB duration ranged from 45 to 118 min (mean: 71 min). The proximal anastomoses were performed under lateral clamping of the aorta before the beginning of CPB.

G and Gii patients were submitted to the same pulmonary function tests during the preoperative period, on 4th and 10th postoperative days (POD and PODii). The test consisted of two parts: spirometry and arterial blood gas measurements. The tests were held in the morning using a 1070 system, series 2E, from Medical Graphics Corporation, www.medgraph.com – St. Paul, MN, USA. Vital capacity (VC) was first obtained with the patient inhaling deeply and exhaling slowly. The volume–time curve (forced spirometry) was constructed according to the criteria of curve acceptability recommended by the American Thoracic Society, and the best of three acceptable curves was chosen. Forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), and forced expiratory flow between 25% and 75% FVC (FEF25–75) were extracted from the volume–time curve. A blood sample was first obtained from the radial or brachial artery and blood gases were measured by the analysis of partial oxygen pressures (PaO2), and partial carbon dioxide pressures (PaCO2). The patient was then asked to breathe for 15 min in a closed circuit into a rubber balloon with 100% oxygen and after this time a new arterial blood sample was collected and blood gases were measured. Alveolar–arterial oxygen gradients (A–aDO2) at 100% was calculated by subtracting PaO2 from alveolar oxygen pressure to determine if there were changes in pulmonary gas exchange.

All patients were submitted to a respiratory physiotherapy protocol in the postoperative period. After extubation a continuous positive airway pressure (CPAP) mask was placed for 20 min each 2 h, during the first 6 h, in order to maintain intra-alveolar pressure and to avoid atelectasis.

The unpaired t-test was applied to compare the absolute mean values of the variables observed during the preoperative period. The mean relative values referring to the preoperative period were calculated on POD and PODii and the data were compared between G and Gii. The observed values were tested by Kolmogorov–Smirnov test for normality, and they were normally distributed. Only tests for comparison between groups were performed.

### 3. Results

During the preoperative period, G and Gii patients presented no difference in absolute mean values for VC, FVC, FEV1, PaO2, PaCO2 and A–aDO2. Only FEF25–75 differed significantly between the groups, with an absolute mean of 2.18 l/s for G, and of 2.69 l/s for Gii (P = 0.043).

On POD, all pulmonary function tests showed alterations compared to the preoperative period in both groups. The mean percentages of these alterations were compared between groups for each index studied.

On PODii, five patients operated upon with CPB (Gii) were not able to perform the pulmonary function test, because their clinical condition did not permit it. On POD10, all the 42 patients (100%) received the tests.

#### Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group-I</th>
<th>Group-II</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>39.62 ± 3.58</td>
<td>50.08 ± 2.45</td>
<td>0.018</td>
</tr>
<tr>
<td>FVC</td>
<td>38.86 ± 3.37</td>
<td>49.95 ± 2.62</td>
<td>0.012</td>
</tr>
<tr>
<td>FEV1</td>
<td>37.69 ± 3.58</td>
<td>48.51 ± 2.26</td>
<td>0.013</td>
</tr>
<tr>
<td>FEF25–75</td>
<td>30.00 ± 5.52</td>
<td>44.46 ± 2.62</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Note: when P < 0.050, the difference was considered to be statistically significant (unpaired t-test).

VC, vital capacity; FVC, forced vital capacity; FEV1, forced expiratory volume in the first second; FEF25–75, forced expiratory flow between 25% and 75% FVC.

#### Table 2

<table>
<thead>
<tr>
<th>Changes in PO2 in relation to the preoperative period and changes in PaO2 (%)</th>
<th>Group-I</th>
<th>Group-II</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaO2</td>
<td>15.17 ± 2.36</td>
<td>16.41 ± 2.35</td>
<td>0.37</td>
</tr>
<tr>
<td>PaCO2</td>
<td>3.68 ± 2.10</td>
<td>10.49 ± 2.40</td>
<td>0.026</td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A–aDO2 100%</td>
<td>225</td>
<td>234</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Note: when P < 0.050, the difference was considered to be statistically significant (unpaired t-test).

PaO2, partial oxygen pressures; PaCO2, partial carbon dioxide pressures; A–aDO2, alveolar–arterial oxygen gradients.

#### Table 3

<table>
<thead>
<tr>
<th>Percent alteration in PO2 in relation to the preoperative period, with comparison of the two groups (mean ± standard error)</th>
<th>Group-I</th>
<th>Group-II</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>24.45 ± 3.11</td>
<td>39.39 ± 2.95</td>
<td>0.005</td>
</tr>
<tr>
<td>FVC</td>
<td>24.23 ± 3.12</td>
<td>39.23 ± 2.88</td>
<td>0.005</td>
</tr>
<tr>
<td>FEV1</td>
<td>22.28 ± 3.11</td>
<td>39.21 ± 2.83</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>FEF25–75</td>
<td>8.93 ± 6.61</td>
<td>37.84 ± 2.91</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: when P < 0.050, the difference was considered to be statistically significant (unpaired t-test).

VC, vital capacity; FVC, forced vital capacity; FEV1, forced expiratory volume in the first second; FEF25–75, forced expiratory flow between 25% and 75% FVC.
All spirometry indices, VC, FVC, FEV\textsubscript{1}, FEF\textsubscript{25–75}, were reduced on PO\textsubscript{10}, but the percentages of alteration in G\textsubscript{1} where lower than G\textsubscript{2}, with significant statistical difference between G\textsubscript{1} and G\textsubscript{2} for all indices (Table 1). There was a reduction in PaO\textsubscript{2} and PaCO\textsubscript{2} and the A–aDO\textsubscript{2} at 100% was increased. Only the PaCO\textsubscript{2} showed statistically significant difference at PO\textsubscript{10} (Table 2).

All indices continued to be altered on PO\textsubscript{10} compared to preoperative values, but there were significant differences between groups, with greater improvement of G\textsubscript{1} (Table 1). In PO\textsubscript{10}, there was still a reduction in PaO\textsubscript{2} and PaCO\textsubscript{2}, and A–aDO\textsubscript{2} at 100% continued high, but with statistically significant difference between G\textsubscript{1} and G\textsubscript{2} (Table 4).

4. Comments

On PO\textsubscript{10}, all spirometry indices were reduced, although the percentages of alteration differed significantly between G\textsubscript{1} and G\textsubscript{2}. On PO\textsubscript{10}, the parameters of spirometry improved in both groups, with significant differences between G\textsubscript{1} and G\textsubscript{2}. Shapiro et al. [5] have reported an average rate of 46.42% in VC alteration on PO\textsubscript{10} which is greater than our results at the same day.

Investigators have reported changes in FVC after the surgery with the use of CPB [8]. In the present study, analysis of FVC data showed that they agree with the literature and that G\textsubscript{1} presented greater improvement than G\textsubscript{2}.

The changes in FEV\textsubscript{1}, reported in the literature for cardiac surgeries with CPB are similar to those of our G\textsubscript{1}, while the values obtained for our G\textsubscript{2} are significantly lower. Some investigators have reported similar changes in FEV\textsubscript{1} in patients operated with the aid of extracorporeal circulation [5].

We ought to remember that G\textsubscript{1} patients had already presented a lower mean FEF\textsubscript{25–75} value than G\textsubscript{2} during the preoperative period (P = 0.043). However, on PO\textsubscript{10}, the reduction of FEF\textsubscript{25–75}, despite the alterations already existing in G\textsubscript{1}, was even greater than in G\textsubscript{2} (P = 0.014). The decrease in FEF\textsubscript{25–75} observed in our patients may be explained by the presence of atelectasis, interstitial edema and general anesthesia itself. There was a noticeable improvement on PO\textsubscript{10} in G\textsubscript{1} patients, indicating that the pulmonary changes were more observed in patients submitted to CPB, and that these patients, despite physiotherapy, continued to have more intense and longer lasting changes in FEF\textsubscript{25–75}. The decrease in FEF\textsubscript{25–75} reported in the literature on-pump surgeries are 40% and 51% [5, 8].

An analysis of PO\textsubscript{10} shows that the greatest difference between the groups occurred in 4th day, as five patients in G\textsubscript{2} did not present any of the necessary clinical conditions to do the tests. On day 4 (PO\textsubscript{10}), 16 patients (76% of G\textsubscript{2}) were submitted to the tests, and the normality of the values was guaranteed for the statistical analysis. Despite this occurrence, we detected statistically significant differences between the groups. We had no way to determine what the results of these tests would have been if patients with postoperative problems had been able to take them.

Several investigators have studied the decline in PaO\textsubscript{2} during the postoperative period of on-pump surgeries [9, 10]. Based on our results, we may state that the mean values of the changes observed in the present study were slightly lower than those reported in the literature, and that both of the groups studied here decreased PaO\textsubscript{2} until PO\textsubscript{10}, although no significant difference was observed between groups.

PaCO\textsubscript{2} suffered small changes, smaller than those observed for PaO\textsubscript{2}. This reduction in PaCO\textsubscript{2} can be explained by the hyperventilation performed by the patient in an attempt to improve PaO\textsubscript{2}, while struggling against the changes in the thorax caused by the surgical incision, such as tissue edema, restriction of expansion, and pain [10].

A–aDO\textsubscript{2} was calculated as 100%. If an alveolo–arterial O\textsubscript{2} gradient occurs under these conditions, it cannot be attributed to low alveolar O\textsubscript{2} tension, but rather to the presence of a shunt. A–aDO\textsubscript{2} has been studied in the literature [11]. The changes observed in our patients showed a significant difference on PO\textsubscript{10} between the groups, which demonstrated an improvement of off-pump patients.

We have to analyze the accumulation of interstitial fluid in the lung after CPB [9], due to the fluid manipulation occurring in CPB itself and also to the systemic inflammatory syndrome [12] caused by blood contact with the CPB circuit.

It is worth considering the requirements of fluid volume during off-pump surgery, in order to maintain hemodynamic stability that Staton et al. [13] referred to, which creates a higher intraoperative fluid balance and reduces the postoperative pulmonary compliance. This is a very important point to be elucidated. In our patients, we did not measure the intraoperative fluid intake nor was the use of diuretics considered. The only control was daily X-rays, which showed less pulmonary congestion in the off-pump group. We believe that a new study has to be done to analyze if off-pump surgery using an intra-coronary shunt, which causes better hemodynamic stability by avoiding regional ischemia during anastomoses, would permit the use of less fluid volume at intraoperative period.

Recently some other authors have studied pulmonary function, comparing off-pump vs. on-pump coronary artery bypass surgery, the results are controversial [14, 15]. It is possible that the different techniques used in off-pump surgery to maintain hemodynamics can be responsible for these differences in studies.

| Table 4 | Changes in PO\textsubscript{10} in relation to the preoperative period and changes in PaO\textsubscript{2} (%) PaCO\textsubscript{2} (%) and A–aDO\textsubscript{2} 100% (mmHg), with comparison of the two groups (mean ± standard error) |
| --- | --- | --- | --- |
| Reduction | Group-I | Group-II | P-value |
| PaO\textsubscript{2} | 2.38 ± 2.99 | 5.77 ± 1.96 | 0.17 |
| PaCO\textsubscript{2} | 6.25 ± 2.48 | 8.77 ± 1.90 | 0.21 |
| Increase | A–aDO\textsubscript{2} 100% | 152 | 216 | 0.019 |

Note: when P < 0.050, the difference was considered to be statistically significant (unpaired t-test).

PaO\textsubscript{2}, partial oxygen pressures; PaCO\textsubscript{2}, partial carbon dioxide pressures; A–aDO\textsubscript{2}, alveolar–arterial oxygen gradients.
5. Conclusions

Measures of pulmonary function deteriorate significantly after coronary artery revascularization with and without CPB, but to a significant greater degree among those on-pump than among those off-pump. Although neither of the groups were found to have returned to baseline pulmonary function at 10 days postoperatively, the off-pump patients showed significant greater improvement than those who had CPB.

References