Inspired Gas Relative Humidity Affects Systemic to Pulmonary Bronchial Blood Flow in Humans*

Piergiuseppe Agostoni, M.D., F.C.C.P; Vincenzo Arena, M.D.; Elisabetta Doria, M.D.; and Giuseppe Susini, M.D.

To our knowledge, the effects of humidity of inspired air on bronchial blood flow in humans are unknown. During total cardiopulmonary bypass, we measured systemic to pulmonary bronchial blood flow (Qbr[s-p]) which is the volume of blood accumulating into the left side of the heart in the absence of pulmonary and coronary flow. A cannula was introduced into the right upper pulmonary vein and advanced into the lowermost portion of the left side of the heart. From this cannula Qbr(s-p) was vented by gravity and measured. Inspired gas (10 L/min, endotracheal tube, 50 percent O2 + 50 percent N2O) relative humidity was <20 percent and >85 percent in group A (n = 25) and in group B (n = 25), respectively. Mean (± SE) Qbr(s-p) was 40.7 ± 0.06 ml/min or 1.32 ± 0.12 ml/min (percent cardiac output) in group A and 21.7 ± 1.8 ml/min or 0.65 ± 0.06 ml/min in group B. These data indicate that under these conditions Qbr(s-p) is increased by dry gas lung inflation in humans. (Chest 1990; 97:1377-80)

\[ Qbr(s-p) = \text{systemic to pulmonary bronchial blood flow} \]

The bronchial tree is involved in the conditioning of inspired air as observed in animal1-3 and human4-6 studies. In the dog, Baile et al3 showed an approximately threefold increase of bronchial blood flow to the trachea and the central airways using dry vs humid air hyperventilation (at constant inspired air temperature). However, the extrapolation of these data to human beings is uncertain, because ventilation is a major thermoregulatory mechanism only in the panting animals. Indeed, during cold air ventilation an increase of bronchial blood flow has been reported in dogs,1,3 whereas a reduction has been suggested in humans.6 In fact, McFadden6 observed paling and shrinking of human bronchial mucosa during cold air ventilation that was assumed to be a sign of bronchial blood flow reduction. Hence, the present study was undertaken to evaluate whether and how bronchial blood flow is influenced by the humidity of inspired air in humans.

METHODS

Fifty patients (eight women and 42 men) were studied while undergoing coronary artery bypass surgery needed because of coronary artery disease. None had lung disease, history of asthma, pulmonary hypertension, heart failure (mean pulmonary artery pressure <20 mm Hg, mean pulmonary artery wedge pressure <12 mm Hg, cardiac index >2.5 L/min/m2 at preoperative cardiac catheterization), or congenital cardiac malformations. The study had been approved by the local ethical committee. Written informed consent to both the surgical and the experimental procedures was obtained from each patient. Total cardiopulmonary bypass was achieved using a previously described technique.7 In brief, blood flowed from a two-stage venous cannula (William Harvey extracorporeal cannula, 34-46 French, Bard) advanced through the inferior vena cava into the right atrium, to an O2 heat exchanger (Oxy 41, Sorin), to the cardiopulmonary bypass pump (HL10, Gambro) and then, through the aortic cannula (21-24 French), back into the aorta. A cannula (18 French) was introduced into the right superior pulmonary vein and advanced in the lowermost portion of the left side of the heart, usually the left atrium. This cannula was connected to a calibrated cylinder placed about 50 cm below the level of the left atrium. The cylinder was connected through a stopcock to a roller pump by which the blood was propelled into the cardiectomy reservoir. Again through the right superior pulmonary vein, a second small cannula (8 French) was placed into the left atrium; this cannula was open to atmospheric pressure, so that left atrial pressure was atmospheric. The patients were cooled systemically and the heart was arrested with cardioplegic solution (about 1,000 ml). During total cardiopulmonary bypass the lungs were kept inflated through an endotracheal tube by a constant flow of gas (10 L/min, 50 percent O2-50 percent N2O) whose temperature was set at 24°C. Airways and systemic blood pressure, pump flow (cardiac output), and inspired gas, esophageal, and rectal temperatures were continuously monitored. Inspired gas temperatures were measured close to the proximal end of the endotracheal tube; this was after the humidifier in group B (see below).

Systemic to pulmonary bronchial blood flow (Qbr[s-p]) was measured as the volume of blood returning to the left side of the heart.7 This blood flowed by gravity into the calibrated cylinder where it was collected continuously during the entire study. Mean Qbr(s-p) was calculated every five minutes. During the first ten minutes of cardiopulmonary bypass Qbr(s-p) was collected, but these measurements were always discarded because of two reasons: (1) the body temperatures of the patient were not stable, and (2) the cardioplegic solution, which was injected in the aortic root, might be mixed with bronchial blood. Indeed, a scanty amount of the cardioplegic solution might briefly drain into the left atrium via the thebesian veins and therefore might be vented mixed with bronchial blood.8 The data reported are those measured during the following 20 minutes before the beginning of patient rewarming. During the surgical procedure cardiac output (pump flow) was

*From the Istituto di Cardiologia, Istituto di Ricerche Cardiovascolari G. Sistini, CNR, Università di Milano (Dr. Agostoni and Doria), Cattedra di Cardiochirurgia, Università di Milano (Dr. Arena), Unità di Anestesia e Rianimazione (Dr. Susini), Fondazione I. Monzino, Milan, Italy. Reprint requests: Dr. Agostoni, Centro di Studio per le Ricerche Cardiovascolari CNR, Via Bonfadini 214, 20138 Milan, Italy.
changed depending on systemic blood pressure. Hence, $\dot{Q}_{br(s-p)}$ is reported as absolute flow and as a percentage of cardiac output.

**STUDY PROTOCOL**

**Group A (n = 25, Mean [± SD] Age 59.2 ± 6.1 Years)**

In this group, 14 patients were smokers, five were nonsmokers, and six were exsmokers, defined as those who had quit smoking at least five years earlier. In group A inspired gas humidification was not performed. On a bench, without a humidifier on the inspiratory line, for a gas temperature of 24°C and a constant inspiratory flow of 10 L/min, inspired gas relative humidity was <20 percent.

**Group B (n = 25, Mean [± SD] Age 62.0 ± 7.1 Years)**

In this group 14 patients were smokers, seven were nonsmokers, and four were exsmokers. In group B inspired gas humidification was obtained by inserting a humidifier (Bennett cascade I humidifier) along the inspiratory line. This humidifier is provided on a bench, for a gas temperature of 24°C and a constant flow of 10 L/min, a gas relative humidity >85 percent. The humidifier was at work since the beginning of assisted ventilation.

**STATISTICAL ANALYSIS**

Data are reported as mean ± SE except as noted. Differences between group A and B were evaluated by unpaired $t$ test.

**RESULTS**

The $\dot{Q}_{br(s-p)}$ measurements started 73 ± 10 minutes and 70 ± 6 minutes after the beginning of assisted ventilation in group A and B, respectively. During the 20 minutes reported $\dot{Q}_{br(s-p)}$ was stable with time. Indeed during the first, second, third, and fourth period (five minutes each) of the 20-minute measurement, mean $\dot{Q}_{br(s-p)}$ was 40.0 ± 4.0 ml/min, 40.9 ± 4.2 ml/min, 40.9 ± 3.7 ml/min and 41.1 ± 3.8 ml/min in group A and 22.8 ± 2.1 ml/min, 21.0 ± 2.2 ml/min, 22.6 ± 1.7 ml/min, and 20.4 ± 1.4 ml/min in group B, respectively. The mean $\dot{Q}_{br(s-p)}$ of each patient, both as milliliters per minute and as a percentage of cardiac output, is reported on Figure 1. Mean systemic blood and airway pressures, cardiac output (pump flow) and inspired air, and esophageal and rectal temperatures were comparable between group A and B (Table 1). In each patient inspired gas temperature changes were <0.2°C and esophageal and rectal temperature changes, limited to the 20 minutes of $\dot{Q}_{br(s-p)}$ measurements, were <1.5°C. Airways pressure was stable during $\dot{Q}_{br(s-p)}$ measurements in both groups and we did not observe any clinical sign of respiratory distress after surgery. The total duration of the cardiopulmonary bypass was 68.4 ± 3.4 minutes and 70.7 ± 4.3 minutes in group A and B, respectively.

**DISCUSSION**

In this study we measured $\dot{Q}_{br(s-p)}$ in humans during total cardiopulmonary bypass and observed that $\dot{Q}_{br(s-p)}$ was about double when the lungs were kept inflated by a flow of dry vs humidified gas.

We measured the portion of bronchial blood flow that drains into the pulmonary circulation. In the dog
Table 1—Hemodynamic Data, Airways Pressure, and Temperatures During Systemic to Pulmonary Bronchial Blood Flow (Qbr(s-p)) Measurements*

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Pressure, mm Hg</td>
<td>69.4 ± 2.9</td>
<td>65.3 ± 2.4</td>
</tr>
<tr>
<td>Cardiac output, ml/min</td>
<td>3,285 ± 593</td>
<td>3,043 ± 151</td>
</tr>
<tr>
<td>Airways pressure, cm H₂O</td>
<td>3.0 ± 0.4</td>
<td>3.2 ± 0.4</td>
</tr>
<tr>
<td>Inspired air temperature, °C</td>
<td>23.8 ± 0.3</td>
<td>23.7 ± 0.3</td>
</tr>
<tr>
<td>Esophageal temperature, °C</td>
<td>27.1 ± 0.4</td>
<td>27.1 ± 0.2</td>
</tr>
<tr>
<td>Rectal temperature, °C</td>
<td>29.4 ± 0.5</td>
<td>29.2 ± 0.2</td>
</tr>
</tbody>
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*Data are mean ± SE; cardiac output = pump flow.

This is about 80 percent of total bronchial blood flow and it is the bronchial blood flow to the intrapulmonary bronchi and lung parenchyma.12 This technique does not measure bronchial blood flow to the trachea and the extrapulmonary bronchi, which are drained, through the bronchial veins, into the right side of the heart.

It is known that bronchial blood flow in the dog is extremely sensitive to inspired air temperature changes12 as well as to body and lung temperature changes. The value of 24°C for inspired gas temperature was chosen to avoid dangerous and undesired lung and heart rewarming and to avoid further lung cooling, both of which might influence Qbr(s-p). To avoid the effects of temperature changes on bronchial blood flow, Qbr(s-p) was measured under stable inspired gas and body temperatures (Table 1). However it should be emphasized that body temperature was, in our study, unphysiologically low and it is known that bronchovascular as well as pulmonary vascular responses to some experimental interventions depend on lung temperature.13,14 Therefore, the extrapolation of the results of this study to human physiology should be done with caution.

During total cardiopulmonary bypass pulmonary flow is absent. Because the pulmonary circulation shares the vasculization of intrapulmonary bronchi with bronchial blood flow,15 it is likely that when the intrapulmonary airways are involved in the conditioning of inspired air, water for gas humidification is provided to the mucosa by both the bronchial and the pulmonary circulations. Indeed, Solway et al16 showed that the pulmonary circulation provides heat for the respiratory heat exchange within the intrapulmonary airways. Therefore, it is possible that the Qbr(s-p) changes we observed have been enhanced by the lack of pulmonary circulation.

The Qbr(s-p) measurements were done 73 ± 10 minutes after the beginning of assisted ventilation in group A, in which humidification of inspired gas was not done, and 70 ± 6 minutes after the beginning of assisted ventilation and inspired gas humidification in group B. Because Qbr(s-p) was stable with time, in groups A and B the time relation between Qbr(s-p) changes and inspired gas humidity changes remains unknown.

During Qbr(s-p) measurements patients were not ventilated, but a constant flow of gas (10 L/min) through a tracheal tube was provided to keep the lungs inflated. We, therefore, bypassed the upper airways and lost the inspiratory mucosal recovery of water. Hence, our setting was again not physiologic and a quantitative analysis of the effects of dry vs humid inspired gas on bronchial blood flow could not be done; possibly, only qualitative information can be drawn from our technique. The evidence is that, at least under the circumstances of this study, Qbr(s-p) increases with dry gas lung inflation in humans. Therefore, our results are in accordance with the observations of Baile et al10 in dogs. Although humidification of inspired gas is usually not done during short-lasting assisted ventilation, our data are in favor of its usefulness. Indeed, it might be helpful to the cardiac surgeons in reducing the blood that has to be vented from the left side of the heart.

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