and the constant improvements in results during the last 50 years are also due to the different ECC techniques that were developed during this long period. At many institutions, off-pump CABG represents about 20% to 30% of cardiac surgical procedures. The remainder of the operations are performed with ECC. We, therefore, believe that further improvement of ECC could improve overall results. In fact, according to our results¹ and the results of Puelher and colleagues, with the MECC is possible to perform a complete myocardial revascularization with the same systemic, cardiac, and clinic results observed with off-pump CABG. Moreover, we think that this system could be safely extended to other, more complex cardiac operations, such as the Bentall operation, aortic valve replacement, ascending aortic replacement, and mitral valve surgery.

Recently, we used the MECC in the cases of 2 patients with a large thrombus of the inferior vena cava as a complication of a left renal tumor. Urologists referred the patients to us, and they preferred to perform the operation during a period of circulatory arrest. We decide to use the MECC for both patients, with the aim of reducing the bleeding. Both cooling and re-warming phases were done with the MECC. Some minutes before the start of arrest (body temperature 20°C), the activated clotting time (ACT) was increased to 480 seconds, and the blood was drained from a different cardiotomy added to the circuit. We observed that blood loss and hemostasis were easy to manage in both patients with 2 large surgical incisions, in the chest and abdomen. Both patients were discharged alive.

Maintaining the ACT around 200 to 300 seconds during the MECC procedure is one of the keys of the system. We have usually used the same ACT target reported by Puelher and colleagues, which is similar to the ACT of our patients operated on off-pump

and is statistically lower than that our patients operated on with ECC. Moreover, in an ongoing prospective randomized trial, we found that patients operated on with standard ECC had more postoperative bleeding and need for more red blood cell transfusions than did those in MECC and off-pump CABG groups.

The concept of a miniaturized system means less biologic and metabolic invasiveness, or in other words, as Puelher and colleagues intend, less hemodilution, better renal and pulmonary preservation, less coagulative disorder, and less inflammatory response. Last but not least, in an era in which coronary surgery on high-risk patients is increasing and many surgeons are afraid to use standard ECC, complete myocardial revascularization with the MECC could be a valid option to achieve good clinical outcome.

Francesco Formica, MD
Cardiac Surgery Clinic
San Gerardo Hospital, Monza,
University of Milano-Bicocca,
Italy

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LUNG VENTILATION/ PERFUSION MAY REDUCE PULMONARY INJURY DURING CARDIOPULMONARY BYPASS To the Editor:

During cardiac surgery with cardiopulmonary bypass (CPB), the surgeon is assured that all organs are perfused and/or protected. The heart—lung machine provides perfusion to all organs while the heart is either cardioplegically arrested or perfused.¹ One assumes that the lungs are perfused, although pulmonary artery blood flow, the major source of blood supply to the lungs, ceases. Discontinuation of pulsatile flow and low mean pressures further accentuate decreased bronchial artery flow. The lung is the “target” organ, especially during prolonged CPB. Severe pulmonary dysfunction, manifested as poor gas exchange, pulmonary edema, and prolonged need for artificial ventilation, are consequences.

Imura and associates² correlated low-frequency mechanical ventilation during CPB in pigs with suppression of ischemic derangements in tissue metabolism and histopathologic changes in the lungs. The technique appears simple and safe and could potentially be used in clinical practice.²

Why have cardiac surgeons not perfused/ventilated the lungs during CPB? Should they? The majority of surgeons were not trained in lung perfusion and most would say that, for short pump runs, the results are excellent. Perfusion of the lungs leads to blood in the operative field and decreases surgical precision. Lung perfusion does not necessarily have to be continuous. Intermittent lung perfusion (pneumoplegia) could be instituted at the same time that the surgeon administers intermittent cold cardioplegic arrest. This would eliminate the problem of visualization and blood in the operative field. A compromise, as suggested by Imura and associates,² is simply to ventilate the lungs in the hope that some gas exchange would occur. Low-frequency ventilation²

FIGURE 1. ETCO₂ recorded in a patient during valve replacement. A, Before cardiopulmonary bypass (CPB) (ETCO₂ = 22 mm Hg). B, During CPB (ETCO₂ = 12 mm Hg). C, After CPB (ETCO₂ = 33 mm Hg). PAW, Peak airway pressure; PEEP, peak expiratory airway pressure; RR, respiratory rate; MV, minute ventilation; TVexp, expiratory tidal volume; ETCO₂, end-tidal carbon dioxide; ETO₂, end-tidal oxygen; FICO₂, inspired carbon dioxide fraction; FIO₂, inspired oxygen fraction; Ppeak, peak pressure.

is beneficial to the lungs of pigs under conditions of CPB. Can that be extrapolated to man?

An important issue to be addressed is whether lung ventilation/perfusion, during conditions of CPB, promotes gas exchange. We³ have performed all valve procedures with the heart beating, perfused simultaneously antegradely and retrogradely with warm blood, and with the lungs ventilated/perfused during the cardiac procedure, in an effort to decrease ischemia-reperfusion injury. End-tidal carbon dioxide (ETCO₂), a measurement of pulmonary blood flow and cardiac output, was continuously monitored. ETCO₂ provides a noninvasive estimate of cardiac output, through the ratio of change in ETCO₂ partial pressure and CO₂ elimination after a brief period of partial rebreathing.⁴ Expired CO₂ is assessed by a noninvasive CO₂ monitor that integrates the differential CO₂ Fick partial rebreathing technique.⁵ Preliminary work shows that ETCO₂ is an excellent indicator of lung perfusion, but its clinical value remains unclear. ETCO₂ continued to be present once CPB was initiated and was unchanged throughout the operations. An example of one valve case is shown in Figure 1. Perfusion/ventilation of the lungs did not interfere with the operation.

Recently, we received institutional review board approval for a prospective randomized clinical trial to evaluate lung perfusion/ventilation during CPB. Results will be forthcoming. On the basis of initial experience by Imura and associates² in pigs and our own experience with humans, in long and complicated procedures, or in patients with pre-existing pulmonary diseases, lung perfusion/ventilation is recommended. Potentially, lung injury can be decreased in these patients.

Francisco Igor B. Macedo, MD^a

Enisa M. Carvalho^a

Edward Gologorsky, MD^b

Tomas A. Salerno, MD^a

^aDivision of Cardiothoracic Surgery

^bDepartment of Anesthesiology

University of Miami Miller School of
Medicine and Jackson Memorial
Hospital, Miami, Fla

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Reply to the Editor:

We thank Dr Macedo and colleagues for their interest in our study on low-frequency ventilation during cardiopulmonary bypass (CPB) that was recently published in the *Journal*.¹ They share our interest in lung injury during cardiac surgery and how to prevent it. We believe this is relevant to current practice with an ever-increasing population of high-risk patients.

The rationale beyond our interest in lung injury is based on the simple observation that in current clinical practice, once CPB is instituted, the patient's lungs are disconnected from the ventilator and left open to the air, fully collapsed and poorly perfused for the duration of CPB. Our report showed significant ischemic damage and atelectasis in the collapsed lungs during and after CPB, and these were improved by using low-frequency ventilation during CPB.¹ Although

the underlying mechanisms are still unclear, there have been reports suggesting that ventilation during CPB may reduce damage in the lungs.² We have taken this forward and are now about to start a large clinical trial to assess low-frequency ventilation in clinical practice.

The issue of pulmonary perfusion during cardiac surgery is an interesting one. Current practice is based on the assumption that bronchial blood supply is sufficient for lung protection during CPB.³ Yet, during cardiac surgery the bronchial circulation (only 1%–2% of the cardiac output) is jeopardized by CPB and surgery-related factors, including lung collapse, internal thoracic artery harvesting, aortic manipulation, hypothermia, and loss of pulsatile flow. Schellensak and colleagues⁴ showed that there is significant decrease in bronchial arterial flow during the initial phase of total CPB and that flow remains low until the end of CPB, returning to normal by 60 minutes of reperfusion.

This highlights the importance that pulmonary circulation may have for alveolar oxygenation, which is also supported by the observation that during lung transplantation surgery the bronchial arteries rarely are reconnected without obvious lung ischemia.

Pulmonary artery perfusion is an obvious potential intervention to prevent lung ischemia. Along with Dr Macedo and colleagues, we are currently focusing on this in ongoing experimental research.

Others have suggested that ventilation during CPB can reduce lung injury.^{4,5} In our view, the safety, efficacy, and surgical practicality of pulmonary perfusion during CPB remains to be proven beyond any doubt before establishing it in clinical practice. Also, there is still a lot of research to undertake to ascertain the mechanistic insights, the dominance of ventilation versus perfusion or vice versa as a protective intervention, and the best route or mode of delivery of pulmonary perfusion.