Changes in Microcirculatory Perfusion and Oxygenation During Cardiac Surgery With or Without Cardiopulmonary Bypass

Nick J. Koning, MD,*† Bektaş Atasever, MD, PhD,† Alexander B.A. Vonk, MD,† and Christa Boer, PhD*

MAINTENANCE OF MICROCIRCULATORY PERFUSION and oxygenation is a prerequisite for preservation of organ function. Studies in the nineties demonstrated gastric mucosal pH, which reflects the level of microcirculatory oxygenation, was clinically diagnostic for the level of disease severity in critically ill patients.[1,2] This pathophysiologic concept was adopted in many studies focusing on acute and chronic microcirculatory derangements in the intensive care setting.[3] The acknowledgement of microcirculatory perfusion derangements as part of the pathophysiology underlying sepsis has led to extension of microcirculation studies to the cardiac surgical setting, as this may reflect the impact of anesthesia, surgery, and cardiovascular complications on patient outcome.[4,5]

In addition to the general impact of cardiac surgery on system hemodynamics, the use of cardiopulmonary bypass (CPB) additionally is associated with a wide range of changes in microcirculatory perfusion and oxygenation. Although off-pump cardiac surgery is considered to be less detrimental for microcirculatory perfusion and oxygenation than surgery with CPB, positioning of the contracting heart during off-pump procedures also may influence the perfusion and oxygenation of the microvasculature.

With the introduction of noninvasive local or regional microcirculatory monitoring techniques to assess microvascular function and dysfunction, including sidestream dark field imaging and reflectance spectrophotometry, more insight has been gained into microvascular changes during and after cardiac surgery. This review discusses alterations in microcirculatory perfusion and oxygenation during cardiac surgery with or without CPB in patients using these local and regional monitoring techniques. The authors particularly describe the influence of perioperative factors on microcirculatory integrity, such as hemodynamic and metabolic parameters, hemodilution, hypothermia, hyperoxia, nonpulsatile flow, and cardiac displacement.

MICROCIRCULATORY PERFUSION AND OXYGENATION

The microcirculation consists of resistance arteries and arterioles (10-450 μm), capillaries (5-14 μm), and venules (8-100 μm), which are covered with endothelial cells secreting anticoagulant and vasodilatory substances. The microcirculation particularly is involved in the exchange of oxygen and carbon dioxide, nutrients, and metabolites between blood and surrounding tissue.[6] In a state of stress, such as hemodilution or inflammation, the endothelium presents its adhesion molecules on the blood-side surface. Consequently, activated endothelial cells result in a procoagulant, vasoconstrictive state, in which cellular blood components may adhere to the vascular wall leading to microvascular obstruction.[7]

A well-known example of microvascular obstruction is the no-reflow phenomenon following coronary interventions, which is multifactorial by nature and involves, among others, endothelial activation, inflammation, microvascular spasm, tissue edema, and thrombus formation.[8] Perfusion abnormalities following microcirculatory obstruction may ultimately lead to reduced hemoglobin oxygenation and oxygen delivery.

Total blood flow delivery to the microcirculation is regulated by a combination of the pressure gradient over the vascular bed, the myogenic response, and resistance to flow as defined by resistance arteries and arterioles.[9] In critically ill patients, it has been shown that alterations in the balance among vasoconstrictors and vasodilators, proinflammatory parameters, and the formation of microthrombi contribute to reductions in microcirculatory pressure regulation and perfusion, leading to impaired tissue oxygenation.[10,11]

In addition to perfusion pressure and microcirculatory flow, local tissue oxygenation is influenced further by the countercurrent exchange of oxygen among crossing arterioles, venules, and capillaries.[12] Moreover, rhythmic flow variations allow for increased oxygen offloading at the venous side of the capillaries during high red blood cell velocities, whereas oxygen would be extracted mainly by cells at the arterial side of the capillary at low red blood cell velocities.[7,13] In case of absent vasomotion during a compromised circulatory state, cells at the venous end of the capillaries consequently would be exposed to oxygen-depleted erythrocytes.

*From the *Anesthesiology and †Cardiothoracic Surgery, Institute for Cardiovascular Research, VU University Medical Center, Amsterdam, The Netherlands.*

Address reprint requests to Christa Boer, Department of Anesthesiology, VU University Medical Center, De Boelelaan 1117, 1081 HV, Amsterdam, the Netherlands. E-mail: c.boer@vumc.nl

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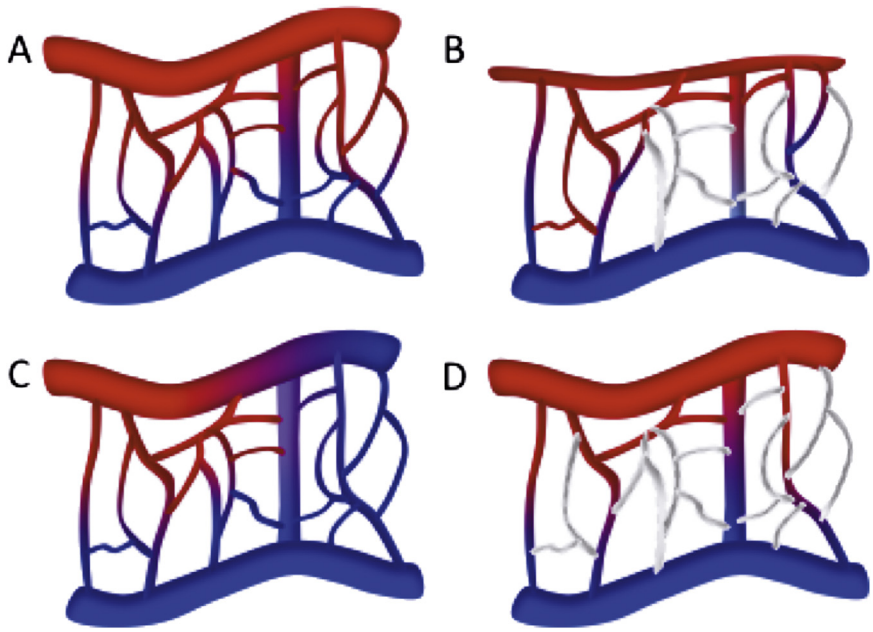

Fig 1. Microcirculatory perfusion profiles. Normal, healthy microcirculation (panel A), diminished diffusive and convective capacity due to arteriolar constriction (panel B), reduction in the convective capacity in case of low hemoglobin oxygenation or hematocrit (panel C) or a decreased diffusive capacity due to microcirculatory perfusion derangements (panel D). Red = oxygenated blood; blue = deoxygenated blood; grey = nonperfused vessels.

The mechanism underlying oxygen delivery often is considered as a combination of diffusive determinants (surface area for exchange, diffusion gradient) and convective determinants (hematocrit, flow). The diffusive determinant includes the passive transport of oxygen down its concentration gradient across tissue barriers, while the convective determinant refers to processes that generate and modulate flow in the macrocirculation or locally through paracrine signaling.[14] Both diffusive and convective mechanisms of oxygen transportation may be disturbed in cardiac surgery. Figure 1 illustrates different microcirculatory perfusion profiles under normal circumstances (panel A) and in a case of a reduced diffusive and convective capacity due to arteriolar constriction (panel B), a drop in convective capacity in case of low hemoglobin oxygenation or hematocrit (panel C), or a decreased diffusive capacity due to microcirculatory perfusion derangements (panel D).

PERIOPERATIVE MONITORING OF MICROCIRCULATORY FUNCTION DURING CARDIAC SURGERY

There are several techniques available for the clinical evaluation of microcirculatory changes in perfusion and oxygenation. In particular, three-dimensional imaging techniques like positron emission tomography, somatic tissue oxygenation measurements, contrast-enhanced ultrasound, and regional cerebral tissue oxygenation measurements by near-infrared spectroscopy (NIRS) generally are integrated in routine clinical practice.[15] In addition, the availability of sidestream dark field (SDF) imaging and reflectance spectrophotometry increased the ability to visualize local microcirculatory perfusion and oxygenation changes during surgery.[16,17]

Measurement Location

Table 1 gives an overview of available local or regional microvascular measurement techniques that can be used in the cardiosurgical setting. SDF imaging, and its predecessor orthogonal polarization spectral imaging (OPS), is a technique to study human sublingual mucosal microcirculation.[18,19] The sublingual microcirculation is the most commonly used location for SDF imaging, although this microvasculature may not always reflect microvascular alterations in other, more vital organs.[20] Others, however, showed that, despite the distance of the sublingual circulation to the heart and central circulation, the sublingual microcirculation is a well-established site to investigate the effects of disease and therapy on microvascular function.[21,22] Moreover, changes in sublingual microcirculatory perfusion are well correlated with alterations in gastric and intestinal beds.[21,22] Alternatively, the rectal microcirculation recently has been proposed as a measurement site that is more closely related to the gastrointestinal circulation.[23]

Reflectance spectrophotometry measures the mucosal blood oxygenation in the terminal network of the microcirculation, but this technique only scarcely has been described for perioperative sublingual microvascular evaluation.[24–26] Alternatively, Fournell et al used gastric reflectance spectrophotometry to measure alterations in microvascular oxygen saturation during CPB.[27] In addition to the local measurement dimensions of reflectance spectrophotometry, NIRS can be used to assess regional tissue oxygenation. NIRS penetrates deeper cerebral or muscular tissue layers and is used routinely to monitor cerebral oxygenation during CPB. NIRS is the most frequently used microcirculatory oxygenation assessment technique during surgical procedures, in particular when decreases in cerebral