Best Practice & Research Clinical Anaesthesiology 29 (2015) 137–149

Contents lists available at ScienceDirect

Best Practice & Research Clinical Anaesthesiology

journal homepage: www.elsevier.com/locate/bean

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# Myocardial injury and protection related to cardiopulmonary bypass

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*Keywords:*
heart
myocardium
ischemia–reperfusion injury
cardiopulmonary bypass
conditioning
cardioprotection

During cardiac surgery with cardiopulmonary bypass, the heart is isolated from the circulation. This inevitably induces myocardial ischemia. In addition to this ischemic insult, an additional hit will occur upon reperfusion, which may worsen the extent of tissue damage and organ dysfunction. Over the years, several strategies have been developed that aim to attenuate and/or modulate the extent of this ischemia–reperfusion injury related to the episode of cardiopulmonary bypass. This article reviews the pathophysiology of myocardial injury related to cardiopulmonary bypass and summarizes potential therapeutic strategies that may modulate the extent of this myocardial injury.



## Introduction

The introduction of cardiopulmonary bypass (CPB) has allowed for the development of cardiac surgery. Indeed, the separation of the lung and heart for surgery, while maintaining adequate flow of oxygenated blood to all the other organs and tissues of the body, has allowed for the surgical correction of even the most complex cardiac conditions. Since its introduction in 1953, CPB techniques have immensely improved and nowadays most patients tolerate the procedure relatively well. Nevertheless, despite major advances in technologies and scientific insights, and despite the implementation of strategies to reduce the pro-inflammatory effects of CPB on the myocardium, the fact remains that during cardiac surgery with CPB the heart is isolated from the circulation and as a consequence suffers

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http://dx.doi.org/10.1016/j.bpa.2015.03.002
1521-6896/

from an ischemic insult followed by an additional hit upon reperfusion, the so-called ischemia–reperfusion injury.

## Mechanisms of myocardial injury related to CPB

Apart from mechanical trauma, both CPB and aortic cross-clamping trigger myocardial injury. CPB provokes a vigorous systemic inflammatory response, induced by the exposure of blood elements to non-physiological surfaces, resulting – among others – in myocardial damage. Furthermore, excluding the heart from the systemic circulation renders the myocardium ischemic, and upon reperfusion, triggers post-ischemic myocardial dysfunction. Central in the pathogenesis of ischemic myocardial injury is the depletion of high-energy phosphates and the disturbance of normal intracellular calcium homeostasis [1,2] (Fig. 1). Upon this period of myocardial ischemia of variable duration, reperfusion may lead to additional injury beyond that generated by the period of ischemia and may manifest as the occurrence of arrhythmias, reversible contractile dysfunction (myocardial stunning), endothelial dysfunction, and ultimately irreversible reperfusion injury with myocardial cell death [3]. The most crucial in the pathophysiology of reperfusion injury is the extent of damage to the mitochondrion, related to the degree of opening of the mitochondrial permeability transition pore (MPTP) [4,5] (Fig. 2).

As a consequence, prevention and treatment of CPB-related myocardial ischemia should not only be directed towards minimizing energy consumption and cellular protection during the period of ischemia but should also include measures to prevent or minimize the extent of reperfusion injury.

## Cardioprotective strategies during CPB: key approaches

### *Preparing the myocardium for CPB*

It is a generally accepted concept that the myocardium should be prepared as much as possible for the period of myocardial ischemia occurring during the aortic cross-clamp. Over the years, different strategies have been explored, some of which seem very logical and straightforward such as the maintenance of hemodynamic stability with avoidance of tachycardia and hypo- or hypertension. Other strategies have been proposed and then were again abandoned because of insufficient proof of clinical efficacy. It is beyond the scope of this review to discuss all these proposed strategies. Table 1 summarizes the principles of the strategies that have been proposed over the years to prepare the myocardium for the induced arrest.

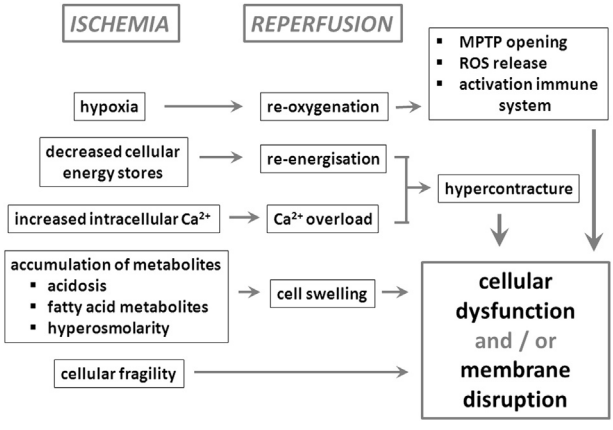


**Fig. 1.** Schematic representation of the different factors contributing to myocardial dysfunction and/or damage with ischemia–reperfusion.