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Ventilator Management and Respiratory Care After Cardiac Arrest

Oxygenation, Ventilation, Infection, and Injury

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Return of spontaneous circulation after cardiac arrest results in a systemic inflammatory state called the post-cardiac arrest syndrome, which is characterized by oxidative stress, coagulopathy, neuronal injury, and organ dysfunction. Perturbations in oxygenation and ventilation may exacerbate secondary injury after cardiac arrest and have been shown to be associated with poor outcome. Further, patients who experience cardiac arrest are at risk for a number of other pulmonary complications. Up to 70% of patients experience early infection after cardiac arrest, and the respiratory tract is the most common source. Vigilance for early-onset pneumonia, as well as aggressive diagnosis and early antimicrobial agent administration are important components of critical care in this population. Patients who experience cardiac arrest are at risk for the development of ARDS. Risk factors include aspiration, pulmonary contusions (from chest compressions), systemic inflammation, and reperfusion injury. Early evidence suggests that they may benefit from ventilation with low tidal volumes. Meticulous attention to mechanical ventilation, early assessment and optimization of respiratory gas exchange, and therapies targeted at potential pulmonary complications may improve outcomes after cardiac arrest.

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More than 500,000 patients experience cardiac arrest in the United States each year.[1] Survival with a favorable neurologic outcome varies highly both by region and cause.[1,2] Among patients who achieve return of spontaneous circulation after cardiac arrest, a number of critical care interventions have been demonstrated to impact eventual outcome, including temperature management, hemodynamic optimization, appropriate neuroprognostication, and meticulous respiratory care.[3-9] Abnormal arterial tensions of oxygen and CO_2 have been associated with poor neurologic outcome after cardiac arrest and may contribute to secondary neurologic injury.[9-19] Early pulmonary infection can be seen in one-half of all patients.[20-24] Additionally, many patients who experience cardiac arrest are at risk for ARDS and may

ABBREVIATIONS: ECLS = extracorporeal life support; PCAS = post-cardiac arrest syndrome; PEEP = positive end-expiratory pressure; ROSC = return of spontaneous circulation

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benefit from therapies known to improve outcomes in ARDS.[8,25,26]

The aim of this review is to describe the optimal approach to mechanical ventilation after cardiac arrest, with the goal of improving neurologic outcome. Specifically, we discuss the evidence supporting prompt normalization of oxygen and CO_2 tensions, low tidal volume ventilation, and prevention of lung injury, as well as aggressive diagnosis of pulmonary infection.

The Post-Cardiac Arrest Syndrome

Return of spontaneous circulation after cardiac arrest often results in the post-cardiac arrest syndrome (PCAS), a state characterized by four key components: (1) brain injury, (2) myocardial dysfunction, (3) systemic ischemia and reperfusion injury, and (4) a persistent precipitating pathologic mechanism.[27] The pathophysiological features underlying PCAS include oxidative stress, coagulopathy, and widespread inflammation leading to multiorgan dysfunction.[20] The brain is particularly sensitive to secondary injury during this period due to alterations in macrocirculatory and microcirculatory blood flow, impaired cerebral autoregulation, and abnormal metabolism.[27-29] Although delivery of oxygen and other metabolic substrates is critical early after reperfusion, hyperoxia may exacerbate free radical production, mitochondrial dysfunction, and neuronal injury.[30,31] Secondary ischemic injury is also common, as patients with PCAS have elevated cerebrovascular resistance and are particularly vulnerable to further injury caused by hyperventilation, as the cerebral vasculature remains sensitive to CO_2.[32,33] Patients who have PCAS are at risk for immune dysregulation, making them more susceptible to infection.[20-24]

A number of interventions have been demonstrated to improve outcome in patients with PCAS, including targeted temperature management and hemodynamic optimization.[3-7] Therapies targeted at ischemia-reperfusion injury, such as immune modulators, neuroprotective agents, and free radical scavengers, have been tested in clinical trials, but none has been demonstrated to improve long-term outcome after cardiac arrest.[34-36] Additionally, maintenance of normal oxygen and CO_2 tensions, aggressive surveillance for pulmonary infection, and ventilation with low tidal volumes have been associated with improved outcome among patients with PCAS.[8,9,11]

Oxygenation

The biological rationale for oxygen management after cardiac arrest attempts to strike a balance between sufficient oxygen delivery to meet the metabolic needs of the cells while avoiding hyperoxia and the potential injury from excess oxygen present during ischemia and reperfusion. Hypoxemia produces ongoing ischemia, irreversible cellular injury, and organ dysfunction, whereas hyperoxemia may increase oxidative stress, amplify free radical production, and worsen organ function. Maintenance of normal oxygen tension may produce optimal clinical outcomes.

A number of preclinical studies demonstrated improved outcome and decreased neuronal injury when animals received lower F_{IO_2} postarrest.[31,37] In an early human study, Kilgannon et al[9] used the Project Impact database, a repository of data from admissions to 120 ICUs in the United States, to examine the relationship between Pa_{O_2} on the initial blood gas determination after ICU admission and outcomes in 6,326 patients.[9] They found significantly higher mortality in the hyperoxemia (Pa_{O_2} > 300 mm Hg) group (63%) than in the normoxemia (Pa_{O_2} 60-300 mm Hg [45%]) and hypoxemia (Pa_{O_2} < 60 mm Hg [57%]) groups. These findings had important clinical implications but also several limitations: The investigators examined only the first available Pa_{O_2} measurement, a high percentage of patients were missing a Pa_{O_2} value (30%), time from return of spontaneous circulation (ROSC) to Pa_{O_2} measurement was not reported, and results were not adjusted for illness severity. In a subsequent study, the same group found that the relationship between Pa_{O_2} and both in-hospital mortality and functional independence was linear.[10] More specifically, they found that each 100 mm Hg increase in Pa_{O_2} was associated with a 24% increase in risk of death.

Multiple subsequent retrospective analyses have been performed to further investigate the relationship between oxygen tension, mortality, and neurologic outcomes in post-cardiac arrest patients, with variable results (Table 1).[13,38-43] In an analysis of > 12,000 patients from 125 ICUs, Bellomo et al[41] found that hyperoxemia was associated with increased mortality in a multivariable model. However, when they controlled for deciles of hyperoxemia, time intervals of Pa_{O_2} results, and redefined hyperoxemia as a Pa_{O_2} > 400 mm Hg, the association between hyperoxemia and increased mortality was no longer significant. Janz et al[38] found

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