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Intraoperative mechanical ventilation for the pediatric patient

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Invasive mechanical ventilation is required when children undergo general anesthesia for any procedure. It is remarkable that one of the most practiced interventions such as pediatric mechanical ventilation is hardly supported by any scientific evidence but rather based on personal experience and data from adults, especially as ventilation itself is increasingly recognized as a harmful intervention that causes ventilator-induced lung injury. The use of low tidal volume and higher levels of positive end-expiratory pressure became an integral part of lung-protective ventilation following the outcomes of clinical trials in critically ill adults. This approach has been readily adopted in pediatric ventilation. However, a clear association between tidal volume and mortality has not been ascertained in pediatrics. In fact, experimental studies have suggested that young children might be less susceptible to ventilator-induced lung injury. As such, no recommendations on optimal lung-protective ventilation strategy in children with or without lung injury can be made.

Introduction

Invasive mechanical ventilation (MV) is required when children undergo general anesthesia for any procedure. Unlike in the intensive care unit (ICU), many patients who receive MV show relatively normal

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pulmonary function and receive endotracheal intubation and controlled ventilation because of the surgical procedure [1]. However, at the same time, the smaller the child the more challenging MV becomes. In addition, pediatric anesthesiologists are being increasingly confronted with pediatric patients having (multiple) comorbidities, which poses a challenge to the intraoperative management. Unfortunately, there is little solid evidence to guide pediatric ventilation practices for patients with or without lung injury [2,3]. Thus, in general, based on their experience in both the pediatric and adult population, pediatric anesthesiologists determine ventilator settings deemed appropriate for the individual patient. “Children are not little adults” is a commonly used catchphrase by pediatric practitioners [4]. Extrapolating the approach in adult practices to pediatrics may not appropriate most of the time. In particular, there are important differences in the pulmonary system, among other factors, between (especially young) children and adults, which justifies a specific approach to pediatric ventilation. Therefore, this review focuses on the intraoperative approach to ventilation for the pediatric patient.

Differences between children and adults

In order to understand how to apply pediatric ventilation across various ages, one must be aware of the differences in the characteristics of the respiratory system between children and adults. In general, early childhood is characterized by rapid development of the lungs, with differing rates of growth observed in the airway, lung parenchyma, and chest wall. In particular, the first year of life is a period characterized by drastic changes. However, it is important to recognize that remodeling of the structural components of the respiratory system is not the same for all components. This concept is known as dysanapsis [5]. Developmental changes in the airways include a reduction in airway resistance (R_{aw}) with increasing height [6,7]. Lung volumes also change during early childhood. Postnatal respiratory development is characterized by a rapid growth of the distal lung compared with relatively steady changes in airway dimensions. Lung compliance (C_{lung}) increases rapidly with increasing height [7]. This is because alveolar multiplication occurs up to the age of 8 years, although recent evidence has suggested that the process of alveolarization may even continue into adolescence [8,9]. Specific lung compliance – that is, lung compliance related to the functional residual capacity (FRC) – reduces during early infancy and remains relatively constant with increasing body length from up to 5 years of age [7,10,11]. This is because FRC increases by a magnitude of 40 times from 80 to 3000 mL in adults [8]. As a function of total lung capacity (TLC), FRC and RV increase with age throughout childhood, while the closing capacity of the lung decreases significantly with age [12,13].

Importantly, there are significant differences in the characteristics of the pediatric chest wall compared to the chest wall in the adult. During infancy, the chest wall is much more compliant. As a consequence, there is less opposition to the tendency of the lung to collapse resulting in low residual lung volume and distortion of the chest wall, and in turn loss of volume during inspiration. The compliance of the chest wall (C_{cw}) is relatively disproportional to the C_{lung} during early childhood, implying that the compliance of the respiratory system (C_{rs}) is about the same as C_{lung} [7,14]. Infants have several respiratory system mechanics to partially compensate for the instability of FRC associated with a compliant chest wall and a tendency for small airway closure during tidal breathing. By modulating their expiratory time, infants are capable of increasing their end-expiratory lung volume (EELV) and maintaining it above the resting lung volume [15]. Furthermore, they may stiffen their chest wall by reducing expiratory flow through post-inspiratory activity of the diaphragm and activation of the inspiratory chest wall muscles [16,17]. During preschool years, the ratio of C_{cw} to C_{lung} decreases by approximately 50%, indicating that the chest wall becomes less compliant due to rib ossification, increasing musculature, and altered chest wall configuration, reaching near-adult values [12,18]. As a consequence, the maintenance of FRC in young children shifts from dynamic elevation of EELV to passive mechanisms achieved by the balance of the outward recoil of the chest wall and the inward recoil of the lung [19].

These developmental changes are clearly influenced by the presence of coexisting comorbidities. For instance, obesity is becoming an increasingly pertinent issue in pediatrics, especially in developed countries. C_{cw}, C_{lung}, and FRC are reduced in obese adults [20]. Similar to adults, FRC is also reduced in obese children [21]. Similar abnormalities in pulmonary function are found in pediatric patients with (neuromuscular) scoliosis.