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Clinical paper

Generation of tidal volume via gentle chest pressure in children over one year old☆,☆☆

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ABSTRACT

Background: In the event of cardiac arrest, cardiopulmonary resuscitation (CPR) is a well-established technique to maintain oxygenation of tissues and organs until medical equipment and staff are available. During CPR, chest compressions help circulate blood and have been shown in animal models to be a means of short-term oxygenation. In this study, we tested whether gentle chest pressure can generate meaningful tidal volume in paediatric subjects.
Methods: This prospective cohort pilot study recruited children under the age of 17 years and undergoing any surgery requiring general anaesthetic and endotracheal intubation. After induction of general anaesthesia, tidal volumes were obtained before and after intubation by applying a downward force on the chest which was not greater than the patient's weight. Mean tidal volumes were compared for unprotected versus protected airway and for type of surgery.
Results: Mean tidal volume generated with an unprotected and protected airway was 2.7 (1.7) and 2.9 (2.3) mL/kg, respectively. Mean tidal volume generated with mechanical ventilation was 13.6 (4.9) mL/kg. No statistical significance was found when comparing tidal volumes generated with an unprotected or protected airway ($p = 0.20$), type of surgery (tonsillectomy and/or adenoidectomy versus other surgery) (unprotected, $p = 0.09$; protected, $p = 0.37$), and when age difference between groups was taken into account ($p = 0.34$).
Conclusions: Using gentle chest pressure, we were able to generate over 20% of the tidal volume achieved with mechanical ventilation. Our results suggest that gentle chest pressure may be a means to support temporary airflow in children.

1. Introduction

Current cardiopulmonary resuscitation (CPR) guidelines suggest a Circulation-Airway-Breathing (C-A-B) sequence on unresponsive victims of cardiac arrest.[1] The circulation component involves downward compressions on the chest to restore and maintain blood circulation. Although still controversial, chest compressions alone have been suggested to be as effective for resuscitation as conventional, three-part CPR in adults. In fact, the American Heart Association (AHA) recommends Hands-Only™ CPR[2] be used for teens and adults who collapse suddenly in an "out-of-hospital" environment. Studies in animal models have shown that chest compression CPR can be as effective as combined ventilation and compression.[3–6] Moreover, several randomized clinical trials have shown that continuous chest compression CPR and conventional CPR have similar outcomes with respect to survival.[7–9]

Although supporting evidence is limited, it is theoretically possible that CPR chest compressions have ventilatory as well as circulatory benefits. During inspiration, the vertical dimension of the chest cavity is increased,[10] generating negative pressure in the intrapleural space and resulting in lung inflation. Once the intrathoracic pressure increases above atmospheric pressure, air flows out of the lungs according to the pressure gradient, and exhalation occurs. Application and release of chest pressure creates passive ventilation by generating supra-atmospheric and negative intrathoracic pressures, respectively. Air is thus forced from the lungs with the application of chest pressure (Fig. 1A) and drawn into the lungs as the chest wall recoils passively upon release of pressure

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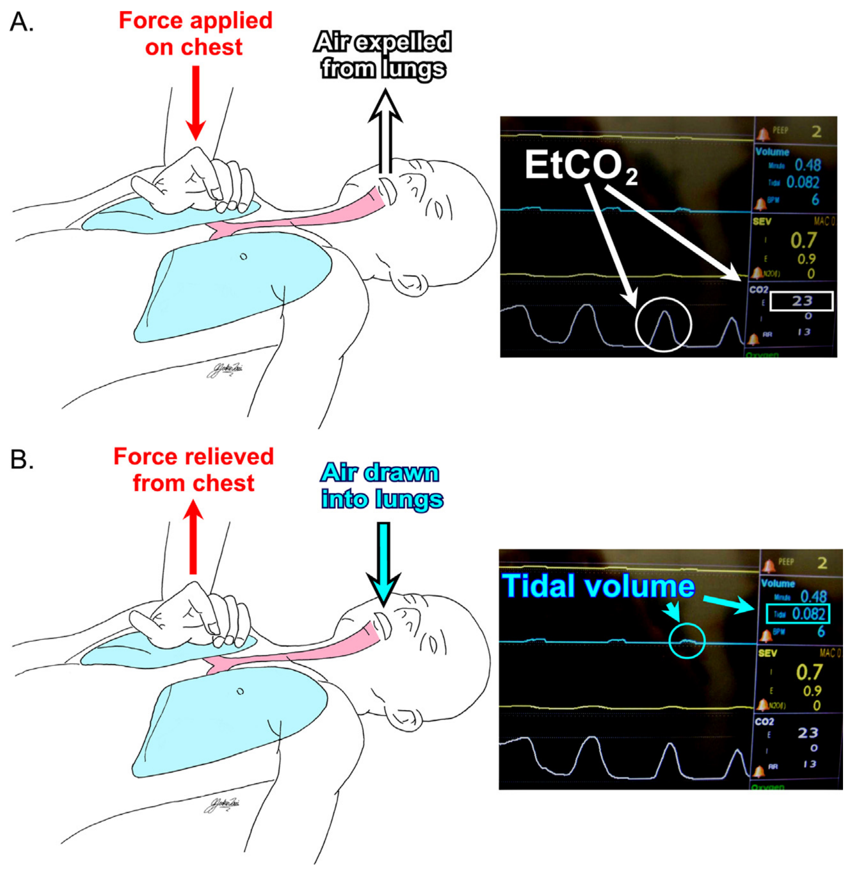

Fig. 1. (A) Schematic drawing of chest pressure ventilation technique showing position of hand on the chest and direction of air upon applying force to the chest. Inset, photograph of monitor showing end-tidal CO_2 ($EtCO_2$) generated with chest pressure ventilation technique. (B) Schematic drawing of chest pressure ventilation technique showing generation of tidal volume upon release of pressure from the chest. Inset, photograph of monitor showing tidal volume generated with chest pressure ventilation technique.

(Fig. 1B). This may be especially beneficial in children since their rib cages are more pliable than adults'. In this study, we assessed whether application of gentle chest pressure and subsequent chest recoil can generate tidal volume (TV) in paediatric subjects.

2. Patients and methods

This was a prospective cohort pilot study. Ethics approval was provided by the University of Alberta Health Research Ethics Board (approval reference #Pro00018804). Inclusion criteria were all paediatric patients (ASA I–III) under the age of 17 years who were undergoing elective surgery requiring a general anaesthetic with an endotracheal tube. Exclusion criteria were the following: failure to obtain parental consent or patient assent when appropriate (in general, children over 6 years of age), patients with any cardiac and/or respiratory pathology, and patients with any chest deformity (for example, pectus excavatum, pectus carinatum, or scoliosis).

2.1. Part A: TV with unprotected airway

Immediately after induction of a standard general anaesthesia (induction technique and decision to administer muscle relaxants was at the discretion of each individual anaesthesiologist responsible for the case), the patient was ventilated with a conventional "bag-and-mask" with 100% oxygen for 30 s. After ensuring the patient was in an apnoeic state, the mask was held over the patient's face and without any airway support devices (e.g., oropharyngeal/nasopharyngeal airway) or techniques (e.g., jaw thrust). Gentle pressure was then applied vertically down on the right chest specifically to avoid cardiac compressions (Fig. 1). The force applied was measured with a transducer (Lafayette Manual Muscle Testing System Model LA-01163, Lafayette, IN, USA) so as not to exceed the patient's actual weight. The downward and upward components of each compression lasted approximately 4 s, and the entire manoeuvre (three compressions) lasted a total of approximately 15 s with 1 s in between compressions.

Tidal volumes generated upon release of pressure on the chest were measured by the spirometry function of the anaesthetic machine (Primus, Drager Medical GmbH, Lubeck, Germany). The minimum detectable volume to trigger the spirometry function of the ventilator was also calibrated. Oxygen saturation was monitored continuously, and, if at any stage the oxygen saturation fell below 95%, the study protocol dictated that the anaesthesiologist return to "bag-and-mask" ventilation. Conventionally, saturations above 90% are considered to provide adequate oxygenation[11]; hence, there is a large safety margin built into the study protocol.

2.2. Part B: TV with protected airway

After measuring TV with an unprotected airway, the patient was ventilated manually with a bag and mask. A suitable size and length endotracheal tube (cuffed or uncuffed, depending on the anaesthesiologist's preference) was inserted into the trachea. With the endotracheal tube in place, positive ventilation was applied to confirm successful proper intubation with bilateral lung inflation. Once satisfactory endotracheal placement was confirmed, the chest pressure manoeuvre was repeated as described in Part A.