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Optimum Compression to Ventilation Ratios in Cardiopulmonary Resuscitation: A Simulation Study

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Abstract

Goal: The purpose of this paper is to investigate optimum compression to ventilation ratios in Cardiopulmonary Resuscitation (CPR). Methods: Mathematical modeling approach is used. Equations describing oxygen, carbon dioxide exchange and blood flow as functions of the compression to ventilation ratio during CPR are developed. The model is validated against normal physiology and animal studies of CPR. Then the model equations are solved to find the optimum compression to ventilation ratios for both professional and lay rescuers. As rescuer performance might vary greatly, Monte Carlo simulations with parameters of rescuer performance randomly chosen are performed to examine whether the optimum compression to ventilation ratios achieved above fit most cases. Results: Results show that the optimum compression to ventilation ratio is around 50:2 for professional rescuers, and is round 70:2 for lay rescuers. Conclusion: The 30:2 compression to ventilation ratio, which is specified in International Guideline, might not be optimum for professional rescuers, might be even worse for lay rescuers. It suggests the 50:2 and 70:2 compression to ventilation ratios might be optimum for professional and lay rescuers respectively. Significance: The 50:2 and 70:2 compression to ventilation ratios might maximize optimum oxygen delivery to body tissue during CPR, and thus lead to better survival rates.

Keywords: Optimum Compression to Ventilation Ratios; Cardiopulmonary Resuscitation; Monte Carlo Simulations; Mathematical Modeling;

1 Introduction

Cardiopulmonary Resuscitation (CPR) is a medical treatment taken to rescue cardiac arrest patients. The quality of CPR delivered has an important impact on success rates [1]. CPR includes chest compressions and ventilations, with chest compression to generate forward blood flow, and with ventilations to deliver oxygen to body tissue.

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Current International Guideline [2] recommends a compression to ventilation ratio of 30:2. That is, the rescuer compresses the chest 30 times, pauses to give 2 mouth-to-mouth ventilations, and then continues with chest compressions. But there is no evidence supporting or refuting whether 30:2 is the optimum compression to ventilation ratio.

Suppose chest compressions are performed at a compression rate of 100/min as recommended in current International Guideline [2]. If a rescuer takes 5 s to deliver 2 mouth-to-mouth ventilations, then with a 30:2 ratio, chest compressions are delivered 78% of the time. In real world, a rescuer may need much longer time, say 16 s to deliver 2 mouth-to-mouth ventilations [3], with a 30:2 ratio, chest compressions are only delivered 53% of the time.

When giving ventilations, chest compressions are interrupted, the forward blood flow generated during chest compression will gradually fall to zero, which has a detrimental effect to oxygen delivery.

Some researchers experiment on other compression to ventilation ratios such as 100:5, 60:2, 100:2 and etc, to see whether they will provide better CPR quality. Kill et al. [4] compare effects of compression to ventilation ratios of 30:2, 100:5, 100:2 and compression only CPR with pig models. Their results find that 100:5 is basically equivalent to 30:2, while 100:2 and compression only CPR reduces the chance of resuscitation success rate. Sanders et al. [5] compare effects of compression to ventilation ratios of 15:2, 50:5, 100:2 and compression only CPR with pig models. Their results find that 100:2 group achieves the best outcome. There are many confounding factors existing in clinical and animal studies, which make these studies hard to repeat, produce conflicting results.

Some studies use mathematical modeling approach to find the optimum compression to ventilation ratio. Tuner et al. [6, 7] show that a compression to ventilation ratio around 20:1 might provide the best resuscitation effects. Babbs et al. [3] show that for professional rescuers, the optimum compression to ventilation ratio is around 30:2, whilst for lay rescuers (who take much longer time to administer rescue breaths than professional rescuers), the optimum ratio is around 60:2.

This paper takes a mathematical modeling approach, equations describing oxygen and carbon dioxide delivery to body tissues and blood flow as functions of the compression to ventilation ratio during CPR are developed. Then the optimum compression to ventilation ratio is calculated after solving the model equations. Since rescuer performance may vary greatly, Monte Carlo simulations were also performed to find the optimum compression to ventilation ratio with varying rescuer performance.

2 Method

2.1 Approach

Glossary of symbols is listed in Table 1.

The lung is treated as a single gas exchange compartment with a 150 ml dead space volume. Rescuer breath with oxygen concentration F_IO_2 and carbon dioxide concentration F_ICO_2 is administered to the lung during CPR. The amount of air administered is determined according to International Guideline. The respiratory rate R, i.e., frequency of ventilations in one minute, is calculated for each compression to ventilation ratio, thus allowing the amount of air administered each minute to be calculated.