Comparison of mask leak and respiratory mechanics in synchronized versus decoupled chest compression in a newborn manikin model

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Research Article

Keywords: Newborn, Chest Compression, Mask Leak

Posted Date: March 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1405843/v1

Abstract

Purpose: Newborn mask ventilation technique requires skills, and effective resuscitation is essential for pulmonary gas exchange. The most effective compression to ventilation (C:V) ratio in newborn resuscitation is still contentious and there is no evidence of human data supporting the current 3:1 ratio. We aimed to study mask leak and respiratory mechanics comparing synchronized and decoupled chest compression on a newborn manikin model.

Methods: Twenty-eight neonatal staff members trained in newborn resuscitation were randomly paired to provide mask ventilation with chest compression in a synchronized (3:1) C:V ratio followed by decoupled chest compression (CC) at a rate of 120 compression to 60 inflations per minute. A Laerdal Advanced Life Support leak-free manikin and a 240-mL self-inflating bag were used. Respiratory mechanical data were collected and analysed.

Results: Decoupled CC provided significantly higher minute ventilation (825.3 mL/min) compared to 534.8 mL/min with the synchronized CC group ($p<0.0001$). The mean mask leak (%) was 27.9 (CI 18.4 – 37.4) in the synchronized CC group and 25.3 (CI 17.6 – 33.1) in the decoupled CC group. Higher mean airway pressure was noted in the decoupled CC group.

Conclusion: Mask leak was unchanged with introduction of decoupled CC to a traditional 3:1 C:V ratio. However, decoupled CC provided significantly higher minute ventilation. Human studies to investigate the respiratory mechanics and hemodynamic effects of decoupled CC are needed.

What Is Known?

- Mask leak is common at newborn resuscitation bag and mask ventilation.
- Maintaining adequate minute ventilation is essential at newborn resuscitation.

What is new?

- Introduction of decoupled CC to bag and mask ventilation leads to significantly higher delivered minute ventilation due to increased inflation rate.
- There is no significant difference in mask leak with introduction of decoupled CC as compared to synchronised CC
- The mean airway pressure is higher with decoupled CC compared to the currently recommended 3:1 C:V ratio.

Introduction

Newborn mask ventilation technique requires skills, and effective resuscitation is premised on establishing adequate mask ventilation to provide pulmonary gas exchange [1]. Lung aeration is especially vital in a sick asphyxiated newborn. Neonatal bradycardia at birth is usually secondary to insufficient lung aeration [2]. Providing positive pressure ventilation (PPV) and maintaining adequate minute ventilation (MV) is essential. Ineffective ventilation and/or airways obstruction at resuscitation in delivery suite is a presumed mechanism for continued neonatal respiratory depression. Leak around the face mask results in inadequate ventilation and often, operators fail to reliably detect leak during PPV, eventually leading to cardio respiratory compromise [3].

The American Heart Association guidelines on neonatal resuscitation recommend a chest compression to ventilation (C:V) ratio of 3:1 in resuscitation of newborn infants based on a mathematical model [4]. Studies have suggested that higher C:V ratio would result in under ventilation of asphyxiated infants [5]. The most effective C:V ratio in newborn resuscitation is still contentious and there is no evidence of human data supporting the current 3:1 ratio. In a newborn manikin model a ratio of 3:1 achieved a greater depth of compression than a 15:2 ratio [6]. Addition of chest compression (CC) to mask ventilation, would result in reduction of minute ventilation (a 3:1 ratio will deliver 30 breath per minute (bpm), compared to 40–60 bpm with ventilation only).

Different C:V ratios have been studied. Solevag et al compared 15:2 versus 3:1 C:V in a piglet model, where the 15:2 ratio did not give a faster return of spontaneous circulation (ROSC) than 3:1 [7]. In the same piglet model of asphyxia there was no difference in ROSC between 9:3 and 3:1 [8]. Recent animal studies also investigated different C:V ratios. A study by Schmolzer using a porcine model compared continuous CC with the current recommendation of a 3:1 ratio [9]. They reported similar ROSC, survival and haemodynamic recovery amongst the groups.

Various manikin studies, including Hemway et al, used 3:1, 5:1 and 15:2 C:V ratios [6]. Providers using 3:1 C:V achieved a greater depth of compressions over a period of two minutes. Similarly Solevag performed C:V ratios of 3:1, 9:3, and 15:2 as well as continuous CC (decoupled 120:40) [10]. MV was significantly reduced at C:V ratios 9:3 and 15:2 compared to 3:1. Continuous CC with decoupled ventilation gave higher MV due to higher ventilation rates. The aim of our study was to compare tidal volumes (TV), MV and mask leak with three different strategies (3:1 synchronized chest compression ventilation, continuous chest compression with simultaneous ventilation (decoupled CC), and bag and mask only ventilation) in a newborn manikin model.

Methods

Participants

We invited neonatal consultants, fellows, senior registrars and neonatal nurses with at least five years of newborn resuscitation experience to participate, 28 of whom consented. All worked in the neonatal intensive care unit (NICU) and were involved with delivery room resuscitation. The study was conducted at Westmead Hospital NICU, which is one of the largest tertiary referral centre for the state of New South Wales, Australia, with over 5000 deliveries annually and more than 1600 admissions to the newborn nursery. The study was approved by the Sydney West Area Health Service Human Research and Ethics Committee (LNR/11/WMEAD/288). Informed written consent was obtained from all study participants.

Devices And Model Used

We used a Laerdal 240-ml self-inflating bag (SIB) with a Laerdal 0/1 round mask (Laerdal Medical, NY, USA) to provide PPV. This SIB has a pop-off pressure release valve set at 35 cm H_2O. A Laerdal® Advanced Life Support (ALS) baby™ manikin model, equivalent to a 3 kg infant. The manikin contains two separate lungs and a stomach with no intended leak. The “oesophageal tube” and “stomach” bag were blocked. The Laerdal manikin has a hinged mandible which allows the jaw-thrust manoeuvre [11]. Prior to each study we measured the static compliance of the model, which was 3.9 ml/cm H_2O. A Florian respiratory function monitor (Acutronics Medical Systems, Zurich, Switzerland) was used to measure the percentage mask leak. A pneumotach was placed between the Laerdal mask and the SIB. Mask leak was defined as: tidal volume inflation (VTi) - tidal volume exhalation (VTe)/(VTi) x 100. MV was then calculated. The manikin was modified with an optical pressure switch attached inside the chest to detect the chest compression. The pressure switch was activated when at least one-third of the antero-posterior diameter of the chest was compressed. This was to ensure that adequate CC was achieved. The signal was collected into the Grove Spectra software (Grove Medical, London, UK) via an analogue signal. Other respiratory mechanics parameters calculated were peak inspiratory pressure (PIP), positive end expiratory pressure (PEEP), mean airway pressure (MAP), inhalation time (Ti) and exhalation time (Te).

Data Recording System

Data from the Florian monitor were collected at 200 Hz via an analogue to digital converting device, using Spectra software. The Florian monitor was calibrated with an external syringe of known volume and pressure/flow via a ventilator calibration analyser. Pressure resolution was 0.1 cm H_2O with pressure accuracy of ± 0.5%, and flow calibration resolution of 0.1L/min with accuracy of ± 1% (RT-200; Timeter Instrument, Allied Healthcare Products, St Louis, MO, USA). An example of decoupled C:V ratio with ventilation is shown in Fig. 1.

Study Protocol

The study participants were randomly assigned to a two-person team. They had extensive skills in neonatal resuscitation and demonstrated proficiency in the locally run newborn resuscitation course, based on the Australian Resuscitation Council (ARC) guideline [12]. Participants were instructed to provide PPV and chest compressions for two minutes with a ratio of one inflation to three compression resulting in 90 CC per minute. Digital clock was used to time the PPV and compressions. After a two-minute rest, the study participants reversed the roles and repeated the same sequence. A standardised one-person mask (two-point top hold) technique was used [3]. Further sequences included performing decoupled CC for two minutes each, which comprised 60 breaths per minute and 120 chest compressions per minute without any pause. The CC rate of 120 was performed based on the mathematical model by Babbs et al which suggested higher rates up to 180/min was needed to provide maximal systemic perfusion [13]. As rate was 180/min was unachievable we performed 120/min.

Data analysis

Data for all studies were extracted from the Spectra software and analysed using Stata® 14 (Stata Corp, College Station, TX, USA). The first five inflations were excluded from the analysis. Analysis of variance was used to examine the differences between PPV with synchronous CC with decoupled CC. Non-normally distributed data were tested with Wilcoxon matched pairs analysis. Mean differences were calculated with 95% confidence interval (95% CI). Differences with a p-value of < 0.05 were considered significant.

Results

Twenty-eight participants in fourteen pairs were studied. A total of 7362 breaths were analysed. Respiratory mechanical data are displayed in Table 1. The inflation rate was significantly higher with decoupled CC as compared to the synchronized CC group. The mean inflation rate was 68.1 (CI 61.3–74.9) in decoupled CC group and 39.1 (CI 35.5–42.6) in the synchronized CC group. The mean VTi was significantly lower in the decoupled CC group (mean difference as compared to the synchronized group, was 8.04 (CI 1.87–14.2, $p = 0.013$). There was no significant difference in the mask leak amongst the group. The mean mask leak (calculated as percentage) was 27.9 (CI 18.4–37.4) in the synchronized CC group and 25.3 (CI 17.6–33.1) in the decoupled CC group (Fig. 2). There was no statistically significant difference in PIP between the groups although higher mean MAP was noted in the decoupled CC group. The mean difference between the group was − 4.01 (CI -5.3 to -2.6 $p < 0.0001$). There was no statistical difference in Ti. The MV was significantly higher in the decoupled CC group. The MV was 825.34 mL/min (CI 712.15–938.52) in the decoupled CC group as compared to 534.85 (CI 460.03–609.67) in the synchronized CC group, with a mean difference of 290.49 (CI -420.3 to -160.7, $p < 0.0001$).

Table 1
Respiratory mechanics amongst synchronized and decoupled CC group and the mean paired differences between the groups.

	Synchronized CC **Mean (SD)**	**Decoupled CC** **Mean (SD)**	**Synchronized CC versus decoupled CC** **Mean difference (SD)**
RR (bpm)	39.1 (35.5–42.6)	68.1 (61.3–74.9)	**-28.9 (-36.4– -21.4)** p **= < 0.0001**
VTi (mL)	65.1 (64.1–66.1)	55.8 (55.2–56.4)	8.04 (1.87–14.2) $p = 0.013$
VTe (mL)	42.4 (36.4–48.4)	39.2 (35.0–43.5)	3.18 (– 4.5–10.9) $p = 0.408$
PIP (cm H_2O)	27.9 (25.0–30.8)	26.1 (23.4–28.9)	1.8 (-2.6–6.3) $p = 0.404$
Mask leak (%)	27.9 (18.4–37.4)	25.3 (17.6–33.1)	**2.57 (-8.2–13.3)** p **= 0.627**
MAP (cm H_2O)	5.0 (4.4–5.6)	9.0 (7.9–10.2)	-4.0 (-5.3 to -2.6) $p = < 0.0001$
Ti (sec)	0.48 (0.42–0.55)	0.45 (0.40–0.50)	0.03 (-0.03–0.11) $p = 0.298$
Te (sec)	1.33 (1.31–1.35)	0.58 (0.57–0.59)	0.69 (0.5–0.9) $p < 0.0001$
MV deflation (mL/min)	534.85 (460.03–609.67)	825.34 (712.15–938.52)	**-290.49 (-420.3 to -160.7)** p **< 0.0001**

Discussion

Perinatal asphyxia is a common cause of need for ventilation and CPR in newborn infants at birth. Maintenance of adequate ventilation and MV is of utmost importance to provide adequate tissue oxygenation. The current ARC guideline recommends synchronized CC at resuscitation for a newborn infant when the heart rate is less than 60 beats per minute. This leads to reduction in the inflation to 30 breaths per minute, which in turn reduces the MV. There are concerns that there would be interference of TV delivery with introduction of decoupled CC [14]. In contrast, interruption in chest compressions with synchronized CC can adversely affect the coronary blood flow and diastolic blood pressure [15, 16]. Introduction of CC in synchronous form as per the current ARC recommendation, leads to drop in MV, and our study demonstrates that significantly higher MV is delivered with decoupled CC [12]. Our manikin study is one of the few to look at respiratory mechanics in a manikin model using different C:V ratios. Boldingh et al reported on respiratory parameters using various C:V ratios and decoupled CC [17]. The MV with decoupled CC was significantly higher (259mls/kg/min) compared to the 3:1 C:V ratio (197mL/kg/min). They achieved a TV of 5–7 mL/kg using different techniques of CPR including decoupled CC, although synchronized CC delivered the highest TV. Our study demonstrates similar higher TV in the synchronized CC group, but the higher inflation rate in the decoupled CC group resulted in higher MV. Similar findings were reported by Solevag et al in a neonatal manikin model using different C:V ratios where they achieved the TV of 4–8 mL/kg in each group with synchronized CC achieving the highest TV [10]. This study did not investigate mask leak with ventilation and its effect on the TV and MV. The effect of higher TV on lung mechanics and pulmonary blood flow needs to be evaluated.

Mask leak is a common occurrence during neonatal bag and mask ventilation. Wood et al reported an average of > 50% mask leak in a manikin model using PPV, irrespective of the experience of the operator [18]. The mask leak is variable with different techniques of mask hold. Tracy et al examined mask leak with one-person versus two-person mask ventilation in a newborn manikin model and reported reduction in mask leak by almost 50% with two-person mask ventilation [19]. Tracy et al showed an increase in mask leak and a reduction in MV with introduction of synchronized C:V ratio to bag and mask ventilation [20]. The MV was reduced from 770 to 451 mL/min ($p < 0.0001$) with introduction of synchronized CC. The current study demonstrates no significant difference in mask leak using synchronous and decoupled CC, which demonstrates the feasibility of decoupled CC.

Recent animal studies have investigated decoupled CC and its effect on pulmonary haemodynamic and ROSC. In a piglet study by Solevag et al, the TV and MV were similar during 3:1 C:V ratio vs. continuous CC with a similar time to ROSC [21]. Li et al published a case report on an extremely preterm infant receiving decoupled CC, with improvement in ROSC [22]. Although our study did not look at hemodynamic we demonstrated that decoupled CC is feasible and further animal and human studies are needed to look at respiratory mechanics and pulmonary haemodynamics with decoupled CC. The current resuscitations guidelines around the world recommends use of decoupled CC in an intubated infant across all paediatric age groups [23]. Our study may be summarised as follows. (i) There is a significant increase in MV in the decoupled CC group compared to the synchronized CC group. (ii) There is no difference in mask leak between the groups. (iii) The decoupled CC group generated a significantly higher MAP with lower PIPs.

Conclusion

Mask leak is common in bag ventilation and CC. The introduction of decoupled CC did not change the mask leak. Decoupled CC provides significantly higher MV compared to traditional 3:1 C:V ratio. Human studies of respiratory mechanics and haemodynamic effects of decoupled CC are needed.

Limitation

Our study was not designed to evaluate the effect of chest compression on the delivered tidal volume. As we used a manikin model comparable to a term newborn lung the effect on cardiac output with decoupled CC could not be evaluated. Our model did not evaluate effect of positive end expiratory pressure using a T-piece resuscitator. This needs to be investigated in further study.

Abbreviations

CC chest compression

CPR cardio pulmonary resuscitation

C:V compression:ventilation

MAP mean airway pressure

MV minute ventilation

PEEP positive end expiratory pressure

PIP peak inspiratory pressure

PPV positive pressure ventilation

SIB self-inflating bag

Te exhalation time

Ti inhalation time

TV tidal volume

VTe tidal volume exhalation

VTi tidal volume inhalation

Statements & Declaration

Acknowledgement

We would like to thank all the study participants at the Westmead Hospital Neonatal Intensive Care Unit, including the medical and nursing staff for their valuable contribution. We would like to acknowledge Ms Claire Galea for the statistical analysis and Ms Olivia Wroth for proof reading the manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material

Not applicable

Code availability

Not applicable

Author Contributions

DS and MT conceptualised, analysed, written, and edited the manuscript, MH and DS conducted the study, NB edited and critically appraised the manuscript

Ethics approval

The study was approved by the Sydney West Area Health Service Human Research and Ethics Committee (LNR/11/WMEAD/288).

Consent to participate

Informed written consent was obtained from all study participants.

Consent for publication

Not applicable

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Figures

Figure 1

Snapshot of recording of positive pressure ventilation and decoupled CC, showing airflow, airway pressure, chest compressions and tidal volume.

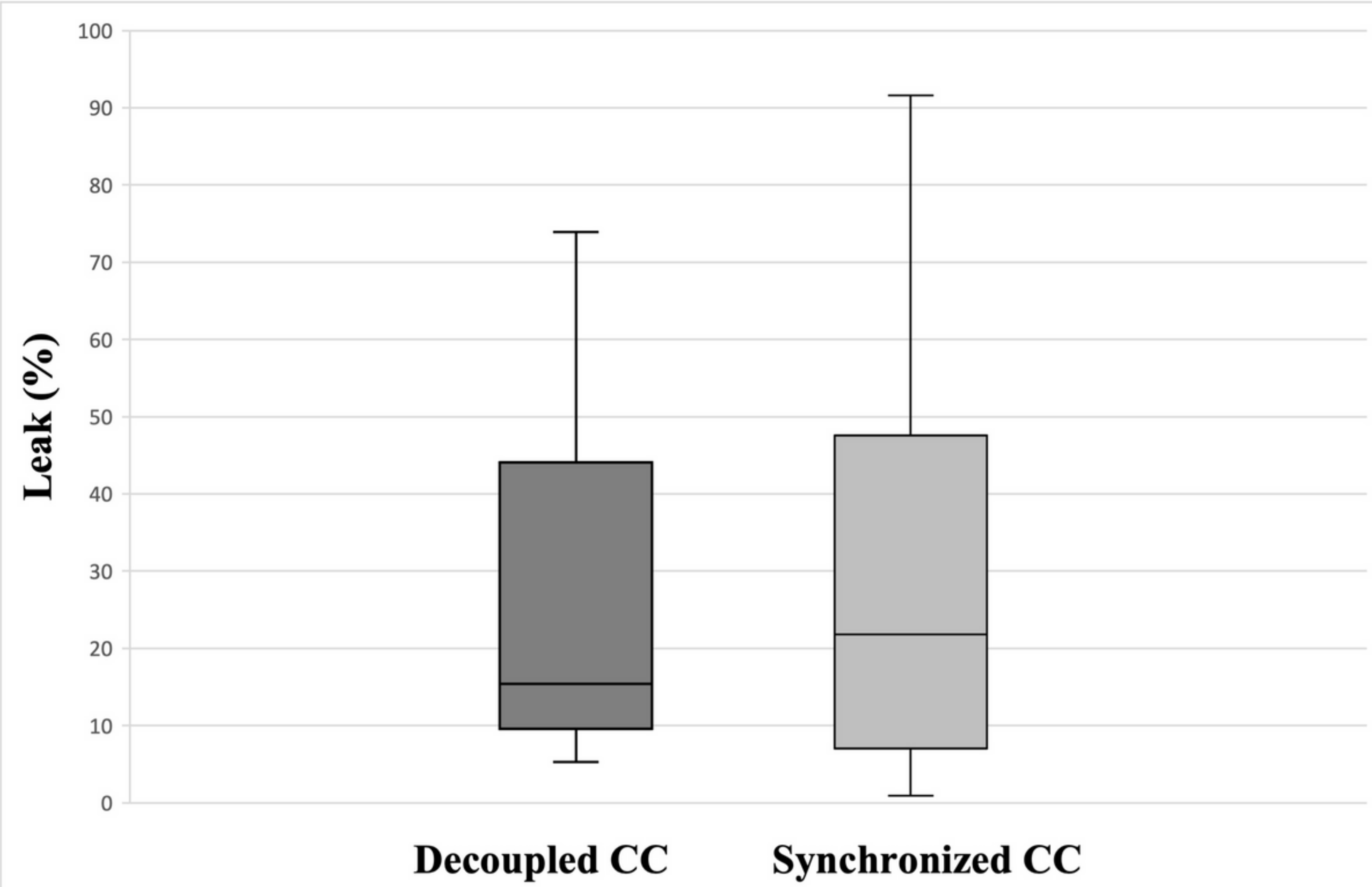

Figure 2

Box plot diagram showing mask leak (%) amongst decoupled and synchronized CC groups.