A metronome for pacing manual ventilation in a neonatal resuscitation simulation

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ABSTRACT

Aim During manual positive pressure ventilation (PPV), delivering a recommended respiratory rate (RR) is operator dependent. We tested the efficacy of a metronome as a standardised method to improve the accuracy of delivered RR during manual PPV in a neonatal resuscitation simulation.

Methods We conducted a blinded simulation in two consecutive stages. Using a self-inflating bag, 36 CPR trained operators provided PPV to a modified neonatal manikin via an endotracheal tube. Pressure and flow signals were captured by a respiratory function monitor. In the first standard stage, participants delivered RR as they would in delivery room. Prior to the second stage, they were asked about what their target RR had been and a metronome was set to that target. Subsequently, operators repeated PPV attempting to coordinate their delivered RR with the metronome. To evaluate accuracy we generated the variable RR Gap as the absolute difference between delivered and target RR. The primary outcome was the difference in RR Gap between stages.

Results Mean (SD) target RR was 50 (8.7) inflations/min. During the initial stage, median (IQR) RR Gap was 11.6 (4.7–18.3) inflations/min and 20/36 participants (55.5%) had a mean delivered RR beyond the recommended range. When paced by the metronome, RR Gap was reduced to 0.2 (0.1–0.4) inflations/min and 32/36 participants (89%) fell within the recommended range.

Conclusions The use of a metronome improved the accuracy of delivered RR during manual PPV. Novel approaches to deliver an accurate RR during manual PPV need to be tested in more realistic scenarios.

What is already known on this topic?

- There are neither validated nor uniformly recommended methods to accurately deliver a given respiratory rate (RR) during manual positive pressure ventilation (PPV) in neonatal resuscitation.
- Real-time monitoring and information regarding respiratory rate are not customarily available to caregivers in the delivery room.
- Several studies have shown that the use of a metronome is an effective strategy to accurately pace chest compressions.

What this study adds?

- A metronome used as a pacing device, significantly reduced the gap between the intended and delivered RRs.
- This also allowed operators to accurately provide the recommended RR range during simulated manual PPV with a self-inflating bag.

INTRODUCTION

During manual positive pressure ventilation (PPV) the International Liaison Committee on Resuscitation recommends a manometer for peak inspiratory pressure (PIP) control and pulse oximetry for heart rate and FiO_2 titration in the delivery room (DR).[1] Monitoring of delivered tidal volume (VT) is also suggested.[2–4] However, strategies to control respiratory rate (RR) are yet to be evaluated.

Although there is not enough evidence supporting an optimal RR range during PPV at birth, International Liaison Committee on Resuscitation current recommendation is to deliver 40–60 inflations/min.[5] Neonatal Resuscitation Program (NRP) instructors usually teach subjective and not validated pacing strategies to deliver the recommended RR, but there isn't any standardised method to accurately provide it.

A metronome is a device used by musicians to keep tempo. It has been evaluated in adult populations to coordinate PPV and chest compressions and in neonatal resuscitation models to evaluate different ventilation/compression ratios.[6–8] The main findings were a lower risk of overventilation and an improvement in the consistency and coordination between inflations and compressions.

The aim of our study was to test the efficacy of a metronome as a RR pacing device in improving accuracy and precision of delivered RR during manual PPV in a neonatal resuscitation simulation.

SUBJECTS AND METHODS

Study population

The study was conducted in Hospital Universitario Austral and Sanatorio de la Trinidad in Buenos Aires, Argentina. Participants were NRP trained paediatrics residents, fellows in neonatology and neonatologists.

Materials

The protocol was performed on a modified full term neonatal manikin (CPR Infant Manikin Baby Buddy Nasco LifeForm, USA) fit with a neonatal test lung (191Neonatal Test Lung, MAQUET, Germany) connected to an endotracheal tube (SilkoClear 4 mm, Rüsch, Teleflex Medical, Germany). The PPV device was a neonatal self-inflating bag (Ambu Mark IV Baby, Ambu, Denmark) with manometer. A respiratory function monitor (RFM) (FluxMed Pediatric, MBMed, Argentina) captured signals by a fixed orifice pneumotachograph placed between the endotracheal tube and the self-inflating bag. Data were downloaded trough FluxView proprietary monitor software via a laptop USB port. Neither the laptop nor the RFM were visible to the operator. The metronome was a digital model with light and sound signals (MA-1, Korg, Japan).

Methods

Operators were blinded to the purpose of the study and to minimise bias they only received written instructions to perform PPV according to NRP guidelines as they would at the DR, with a PIP target of 25 cm H_2O. Participants remained silent during data recording and distractions were avoided.

Each participant performed four PPV series of 90 s. During the first two series, designated as Standard Stage (STD), operators delivered RR as they usually do in the DR. Afterwards, we asked them what their target RR (tRR) had been and this was used to set the metronome. For the next two series, designated as Metronome Stage (MNM), operators repeated the procedure coordinating their delivered RR (dRR) with the metronome. Both stages were always carried out in the same order to protect blinding. All participants practised until they felt comfortable with the metronome before beginning the recording and had an interval of at least 1 min in between series to avoid fatigue.

Ethics and participant consent

Operators volunteered to participate. Their performance information was anonymous and kept confidential. The IRB from Universidad Austral evaluated the protocol and an informed consent was not deemed necessary.

Outcome variables

We tested the metronome by comparing accuracy and variability of RR during PPV at both stages. To evaluate accuracy we generated the variable RR Gap as the absolute difference between dRR and tRR. The primary outcome was the difference in RR Gap between stages. To evaluate if RR pacing could interfere with other PPV variables we measured PIP, VT, minute ventilation, inspiratory and expiratory times, inspiration/expiration (I/E) ratio, and mean airway pressure at both stages.

Sample size estimation

Using data from previous manual PPV simulation studies[9 10] a sample size of 36 operators was calculated to detect a difference of at least 10 inflations/min between gaps considering a two-tailed significance level of 0.05 and a power of 80%.

Data management

Our RFM software calculates RR inflation by inflation. Only data from the central 60 s of each series were analysed. For STD and MNM, acquired data from the two series were averaged to obtain single operator means.

Statistical analysis

We performed paired Wilcoxon signed rank test to compare RR Gaps and other PPV variables at both stages, and Spearman's correlation test between dRR and tRR. Variability of dRR was evaluated through median coefficient of variation. Analysis was performed using IBM SPSS Statistics V.19.0.0 (IBM Company, Armonk, New York, USA).

RESULTS

We analysed 6482 inflations from 36 participants (22 neonatologists, 3 fellows and 11 pediatricians) where 58% had a level of experience equal to or more than 5 years. There were no refusals to participate.

The mean chosen tRR was 50.4 inflations/min (SD 8.7). During STD median (IQR) RR Gap was 11.6 (4.7–18.3) inflations/min and 20/36 participants (55.6%) delivered RR beyond their recommended range (14(38.9%) below 40 and 6(16.7%) above 60 inflations/min). With the metronome, the RR Gap was reduced to 0.2 (0.1–0.4) inflations/min ($p<0.001$) while dRR of 32/36 participants (89%) fell within the recommended range (table 1 and see online supplementary figure S1).

The correlation between tRR and dRR rose from $\rho=0.47$ ($p=0.004$) in the STD to $\rho=0.99$ ($p<0.001$) in the MNM. Regarding variability, the dRR coefficient of variation was higher during STD (table 1). There was a significant reduction on inspiratory time, VT and mean airway pressure and I/E ratio shortening in the MNM. PIP, expiratory time and minute ventilation remained constant through both stages (table 1).

Table 1 Respiratory rate gap and respiratory variables compared at both stages

	STD*	MNM*	p Value†
dRR (infl/min)	44 (31–52)	50 (40–60)	0.099
RR Gap (infl/min)	11.6 (4.7–18.3)	0.2 (0.1–0.4)	<0.001
Ti (s)	0.44 (0.32–0.72)	0.33 (0.28–0.41)	0.006
Te (s)	0.92 (0.56–1.24)	0.78 (0.67–0.95)	0.282
I/E ratio	0.5 (0.34–0.64)	0.4 (0.29–0.6)	0.035
VT (mL)	32 (28–38)	28 (24–35)	0.008
MV (L/min)	1.5 (1.19–1.65)	1.5 (1.18–1.74)	0.475
PIP (cm H_2O)	27.6 (20–30)	26.7 (20–31)	0.671
MAP (cm H_2O)	7.4 (5.5–9.9)	6.7 (4.3–9.8)	0.005
dRR CV (%)	42.2	17.7	–

*Median (IQR).
†Wilcoxon paired signed rank test.
CV, coefficient of variation; dRR, delivered respiratory rate; MAP, mean airway pressure; MNM, Metronome Stage; MV, minute ventilation; PIP, peak inspiratory pressure; RR, respiratory rate; STD, Standard Stage; Te, expiratory time; Ti, inspiratory time; VT, tidal volume.

DISCUSSION

In our study, the metronome improved accuracy and precision of delivered RR. In addition, we observed that during STD, while trying to achieve the range with which they were trained, operators showed a high variability, and that a large proportion extended their delivered RR outside the recommended limits.

Advanced resuscitation at DR is rare and, in approximately two-thirds of cases, is due to ineffective or improper initial ventilation.[11] However, the early detection of failures can be difficult without monitoring devices. Several studies have demonstrated that colour assessment is not a reliable proxy for O_2 saturation[12] and that experienced NRP providers are unable to accurately determine heart rate whether using auscultation or palpation techniques.[13 14] There are no studies evaluating the potential effects of delivering an inadequate RR, but the evidence shows high operator-dependent variability and a propensity to deliver higher RR than recommended.[9 15 16] Delivering a RR below 40 inflations/min was, during the STD, more frequent than reported. Either for ventilating above or below the limits, it is worrisome that many providers fail to achieve the RR range with which they were trained. So, as for other variables in the DR, objective strategies to deliver an accurate RR could be further evaluated.

Previous metronome studies are related to chest compression pacing and only marginally comparable with our results.[6–8] To our knowledge, this is the only blinded simulation study about neonatal manual PPV aimed to RR pacing. The self-inflating bag was selected because of its longer usage history in the DR[17]; however the T-piece resuscitator should be evaluated. Several authors described gas leak during manual PPV through face masks.[18 19] We preferred an endotracheal tube to avoid leaks which could under-report RR. PPV was performed in short and repeated series to minimise fatigue bias and enhance the quality of data related to intrinsic variability; however, we did not find a statistically significant difference between series in any participant. This study has several limitations related to its design that could overestimate the effect of metronome pacing. Our results were obtained in a simulated environment and should be interpreted cautiously since things could be different in real life scenarios. Distractions may affect PPV performance[16] so, to minimise potential confounders, in this first approach to metronome pacing we elected a quiet and stress-free environment. It is of concern that even in this setting and in standard conditions, most participants failed during the STD to deliver a RR close to their target and within the recommended range. We speculate that in stressful conditions, providing an accurate RR without any objective guide could be even harder.

The metronome is an inexpensive and portable device. Minimal training is required for its use as a RR pacer. This simple and low cost technology could improve manual PPV worldwide, even when a RFM is not available.

So, to provide gentle yet effective ventilation in the DR, improving accuracy and precision of delivered RR with a pacing device could improve PPV and perhaps reduce the needs to escalate in CPR interventions.

CONCLUSIONS

In our study the use of a metronome improved the accuracy of delivered RR, allowed keeping it within the recommended range and reduced operator dependent variability. Novel approaches to accurately deliver RR during manual PPV, such as a metronome, deserve consideration and further studies in more realistic simulations and real life scenarios.

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Competing interests MM is a PhD fellow in Instituto Tecnológico de Buenos Aires (ITBA), Argentina. He designed the Fluxmed respiratory function monitor and software used in the study and is a stockholder of MBMed. Nevertheless the company did not participate in study design, recruitment or manuscript writing.

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