Hard and fast, but within limits: is there a trade-off of stroke volume index and diastolic pressure in paediatric resuscitation?

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Dear Editor,

The aim of chest compressions in cardiopulmonary resuscitation (CPR) is to restore organ perfusion while maintaining adequate coronary perfusion. The effects of force and rate of compressions are derived from animal studies; human data, especially from children, are scarce. A 3.5-year-old, 22-kg boy with ARDS received chest compressions for hypoxic cardiac arrest. Diastolic blood pressure (DBP, mmHg) was measured invasively and stroke volume index (SVI, mL/m^2) was estimated using LiDCO*rapid*® (Lidco Group Plc, London, UK) pulse contour analysis from the child's indwelling right axillary arterial catheter [1]. One minute of representative compression data was recorded from two rescuers, who compressed manually through a force-sensing mat on the child's sternum (Tekscan Inc®, Boston MA, USA). The rescuers received no performance feedback above standard monitoring. Compressions were manually synchronised with the beat-to-beat haemodynamic data. Uni-variable and multivariable linear regression analyses of maximum force in newtons (F_{max}, N), leaning force (F_{min}, N) and time period between consecutive compressions (TP, s) were used to evaluate the effect of compressions on SVI and DBP.

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Rescuer 1 applied 51 N (SD 6 N) mean force at a rate of 97 compressions per minute (cpm), Fig. 1a. Rescuer 2 delivered greater forces: 137 N (SD 15 N) at 126 cpm. The second rescuer also maintained a larger F_{min} mean (SD) 22 N (4 N) versus 7 N (0.7 N). Absolute forces were lower than reported with different technologies [23]. Maximum force and F_{min} demonstrated co-linearity, so change in force was calculated ($\delta F = F_{max} - F_{min}$).

Fig. 1

a Chest compression force–time profile collected during an actual paediatric cardiac arrest. *cpm* compressions per minute. The thin Tekscan® mat was placed on the lower sternum to record manual force (in newtons) with each compression. A representation of the variables measured during compressions is included. The graph shows force measured over

1 min of resuscitation by two rescuers. Rescuer 1 used lower forces and rate of compressions; rescuer 2 used both greater F_{max} and F_{min} at a faster rate. The child received noradrenaline and adrenaline during repeated arrests. The force data are limited to 1 min as the machine erroneously defaulted to a factory setting which allowed only this duration of data collection. **b** Relationship of stroke volume index with chest compression force during resuscitation. The broken horizontal line represents baseline, pre-arrest stroke volume index. Most compressions produced a stroke volume index greater than baseline, higher values being demonstrated by rescuer 2. The LiDCO*rapid*® was calibrated 8 h before the arrest using the cardiac index value obtained with a suprasternal ultrasound cardiac output monitor (USCOM®, USCOM Ltd, NSW, Aus). Baseline SVI and DBP were determined retrospectively by analysing and averaging 1 min of data 1 and 2 h before the arrest occurred

Baseline pre-arrest SVI was 31 mL/m^2 (SD 1.2 mL/m^2), Fig. 1b. During compressions, SVI increased with applied force. Mean (SD) SVIs for rescuer 1 and 2 were 34.5 mL/m^2 (1.5 mL/m^2) and 46.1 mL/m^2 (10.6 mL/m^2), respectively. On multivariable analysis, each additional newton of δF increased SVI by 0.18 mL/m^2 (95% CI 0.09–0.27 mL/m^2, $p < 0.001$). TP did not predict SVI ($p = 0.5$).

Baseline pre-arrest DBP was 43 mmHg (SD 1.4 mmHg). Mean (SD) DBPs for rescuers 1 and 2 were 15 mmHg (1.8 mmHg) and 12 mmHg (2.9 mmHg), respectively. On multivariable analysis, DBP rose by 19 mmHg per second increase in TP (95% CI 9–28 mmHg, $p < 0.001$), whereas δF was not associated with DBP ($p = 0.3$).

These novel, surprising observations suggest the following: (a) wide ranges of forces were associated with SVI equivalent to or greater than the pre-arrest baseline. (b) Within the recommended rate range, rate did not affect SVI. (c) As rate slowed (TP increasing), so DBP rose, contrary to animal evidence [4]. This may reflect the higher F_{min} (indicating incomplete compression release) demonstrated by rescuer 2.

Given this potential trade-off between rate and force in achieving optimal DBP and SVI, ideal values for paediatric rate and force are required [5]. This example merits future study, suggesting that in addition to rate and DBP, performance and potentially outcome may improve with additional real-time force and SVI feedback.

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Compliance with ethical standards

Ethical approval

Ethics approval was granted by the National Research Ethics Service Committee (registration number 12/LO/1700, protocol v.1), for recording compressions during CPR in a child in a tertiary paediatric hospital. Permission was granted to collect the data automatically during an arrest and to obtain retrospective written, informed consent from the family and from the rescuers to analyse and present the data.

Conflicts of interest

The authors declare they have no conflict of interest.

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Proof Review

- No Correction