# Supplementary materials

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## OBSERVED VENTILATION RATES

Several studies have reported ventilation rates during CPR exceeding the recommended values of $10\,\mathrm{min}^{-1}$ [1]–[3]. In fact, some recent studies observed ventilation rates above $10\,\mathrm{min}^{-1}$ in 85% of patients [3]. Upon revising the ventilation rates during mechanical CPR in our dataset the observed rates were well below $10\,\mathrm{min}^{-1}$, with a median (interdecile IDR range) ventilation rates per patient of $6.0\,(3.8-10.6)\,\mathrm{min}^{-1}$. In fact, the ventilation rate only exceeded the $10\,\mathrm{min}^{-1}$ value for 12.5% of our patients. A detailed account of the distribution of the per-patient ventilation rate is shown in Fig 1.

A close inspection of the ventilation patterns in our data revealed some interesting characteristics. The typical ventilation patterns observed in patients in which ventilation rates were low are shown in Fig 2. They can be grouped into: (1) ventilations provided following a 30:2 compression to ventilation pattern during continuous chest compressions (see Fig 2a), (2) spaced-out ventilations with long ($10-20\,\mathrm{s}$) intervals between consecutive ventilations (see Fig 2b), and long periods of up to 1-min without ventilations (see Fig 2c). All these cases consistently produced ventilation rates below 6-7 $\mathrm{min}^{-1}$, with extreme intervals of 1 or 2 ventilations in a minute (see Fig 2c).

The ventilation rates for the typical 30:2 CPR pattern would normally results in ventilation rates around $6\,\mathrm{min}^{-1}$. At a chest compression rate of $100\,\mathrm{min}^{-1}$, the rate fixed by the LUCAS2 device, a 30 compression sequence would last 18 s. So that would leave room for approximately 3 ventilation intervals in a minute. In fact, a recent study reports an average ventilation rate during 30:2 CPR of $7\,\mathrm{min}^{-1}$ [4]. And classical studies on CPR quality have reported ventilation rates of $8\,\mathrm{min}^{-1}$ in the early stages of advanced life support [5], that is before intubation and for CPR delivered at either 15:2 or 30:2 compression to ventilation ratios[1]. So our the findings in our data are consistent with these results, although it is surprising that rescuers keep the 30:2 compression to ventilation ratio both after intubation and after the initiation of mechanical CPR. Moreover, in some cases the 30:2 ratio degenerated into 30:1 ratios, which produced very low ventilation rates of 3-4 $\mathrm{min}^{-1}$. A typical example is shown in Fig 3.

Finally, in many occasions the observed ventilation rates were in line with the guidelines recommendations, some typical examples are shown in Fig 4a and Fig 4b. And as reported in other studies we also found some extreme values of ventilation rates higher than $20\,\mathrm{min}^{-1}$, as shown in the example of Fig 4c.

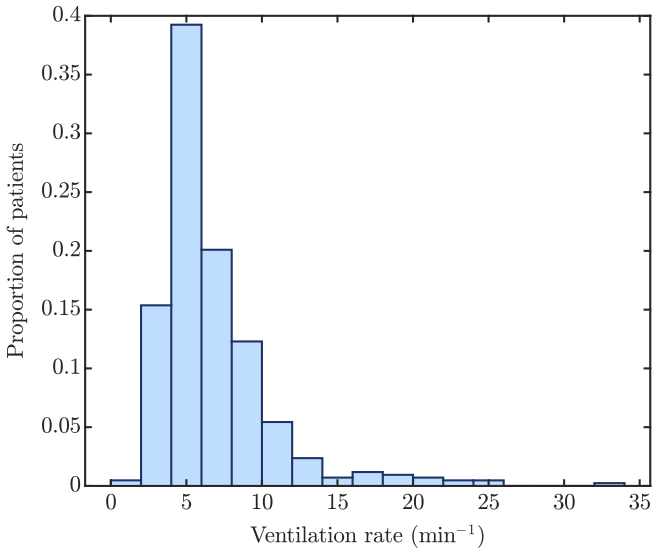


Fig. 1: Distribution of the ventilation rates per patient during mechanical CPR in our data cohort.

## REFERENCES

[1] T. P. Aufderheide and K. G. Lurie, "Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation." *Critical care medicine*, vol. 32, pp. S345–S351, Sep. 2004.

[2] J. F. O'Neill and C. D. Deakin, "Do we hyperventilate cardiac arrest patients?" *Resuscitation*, vol. 73, pp. 82–85, Apr. 2007.

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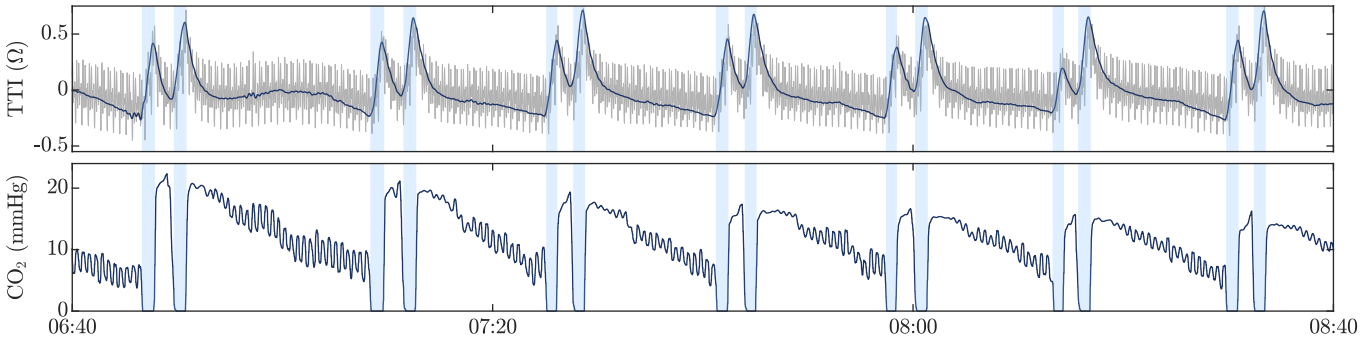
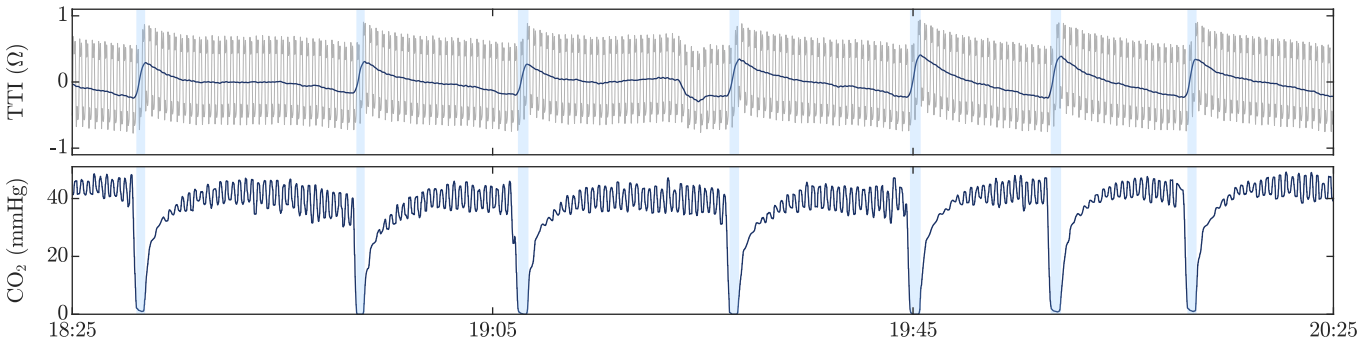
[4] G. Sanson, G. Ristagno, G. D. Caggegi, A. Patsoura, V. Xu, M. Zambon, D. Montalbano, S. Vukanovic, and V. Antonaglia, "Impact of 'synchronous' and 'asynchronous' cpr modality on quality bundles and outcome in out-of-hospital cardiac arrest patients." *Internal and emergency medicine*, vol. 14, pp. 1129–1137, Oct. 2019.

[5] L. Wik, J. Kramer-Johansen, H. Myklebust, H. Sørebø, L. Svensson, B. Fellows, and P. A. Steen, "Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest." *JAMA*, vol. 293, pp. 299–304, Jan. 2005.

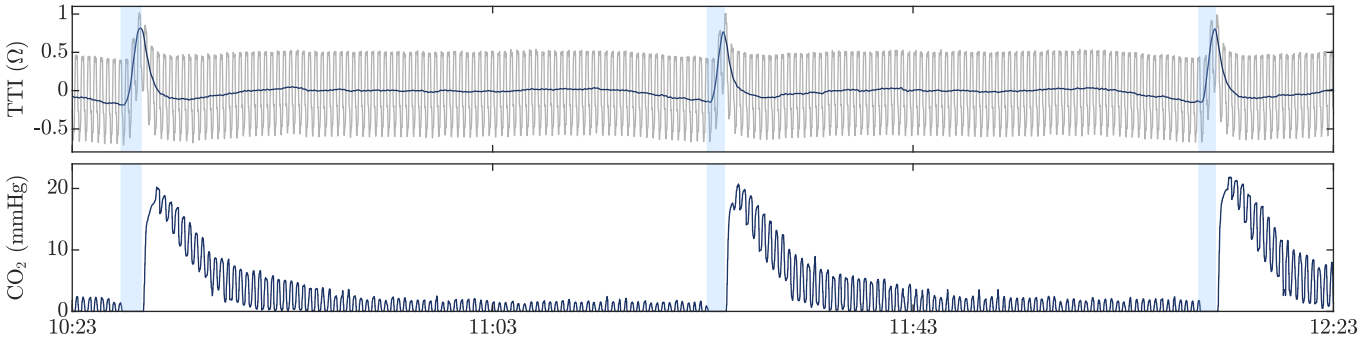
[1]The recommendations for 30:2 CPR was established in the 2005 resuscitation guidelines




(a) Ventilations delivered following a 30:2 CPR pattern during mechanical CPR, ventilation rate 7 $\mathrm{min}^{-1}$.




(b) Very slow ventilation rates of 3-4 $\mathrm{min}^{-1}$, with ventilations delivered every 15-20 s.




(c) Long time intervals of up to 1-minute without ventilations, with ventilation rates of 1.5 $\mathrm{min}^{-1}$.

Fig. 2: Examples of 2-minute uninterrupted mechanical compressions with low ventilation rates. The lower trace shows the capnogram with actual ventilations when the curve falls to 0 (insufflation phase). The upper trace shows the impedance without baseline level with the compression and ventilation activity in grey, and the ventilation component in blue.

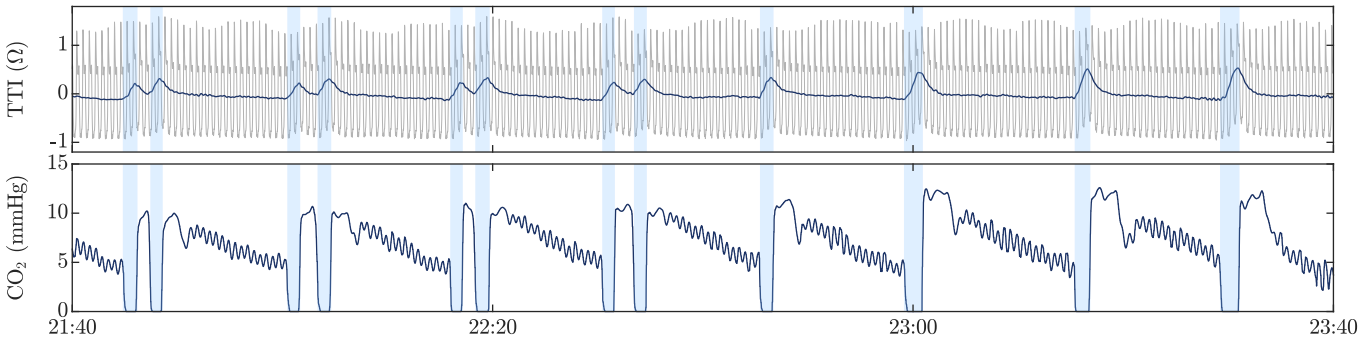
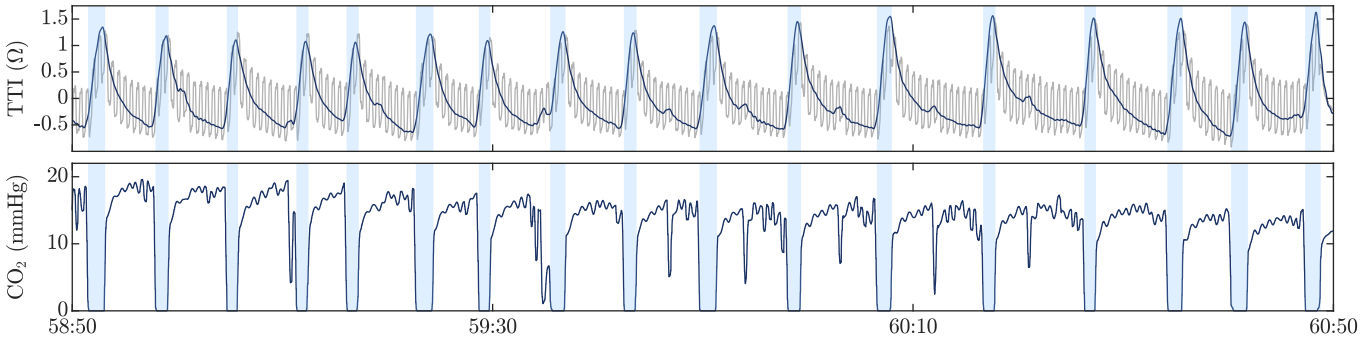
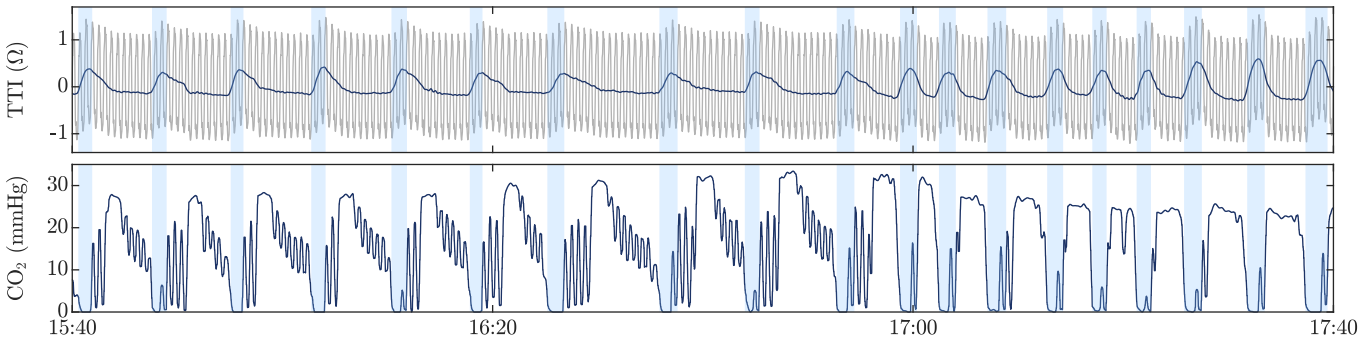


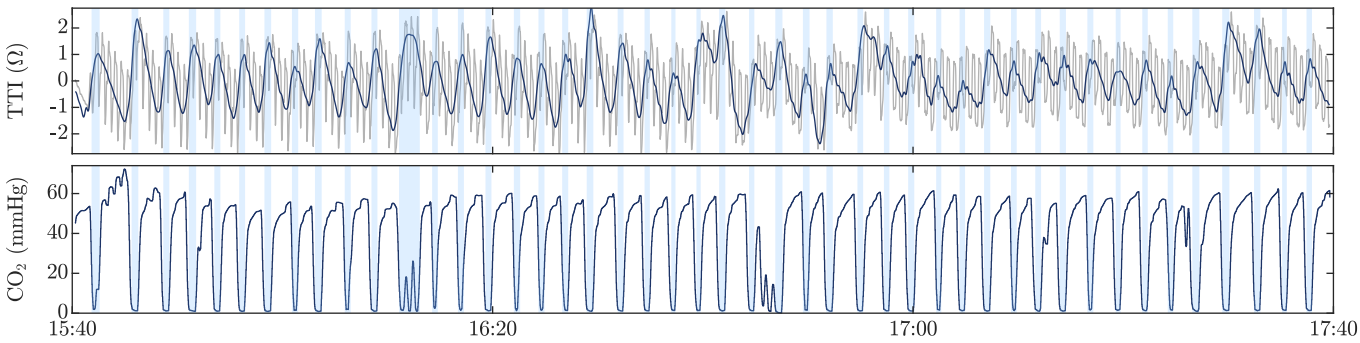

Fig. 3: Examples of 2-minute uninterrupted mechanical compressions in which the ventilation pattern evolves from 30:2 CPR to 30:1 CPR, with rates going from 6-7 $\mathrm{min}^{-1}$ to 3-4 $\mathrm{min}^{-1}$.




(a) First example of ventilations provided at the recommended rate of 10 $\mathrm{min}^{-1}$.




(b) Second example of ventilations provided at the recommended rate of 10 $\mathrm{min}^{-1}$.




(c) Example of a hyperventilated patient, with a ventilation rate of 23 $\mathrm{min}^{-1}$.

Fig. 4: Examples of 2-minute uninterrupted mechanical compressions with normal or hyperventilation rates.