

# Non-Invasive and Continuous Blood Pressure Monitoring Using Deep Convolutional Neural Networks

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**Background:** In 90% of surgeries and 66% of ICU patients, arterial blood pressure (ABP) is monitored non-invasively but intermittently using a blood pressure cuff. In the remaining 10% of surgeries and 33% of ICU patients, ABP is measured continuously but invasively. Since even a few minutes of hypotension increase the risk of postoperative mortality, and because invasive monitoring is associated with major complications (infection, bleeding, thrombosis, pain), the ideal ABP monitor should be non-invasive and continuous. We report the development, training, and validation of a novel, non-invasive method for imputing the arterial blood pressure waveform and its derived systolic, diastolic and mean values using the ECG waveform, the PPG waveform, and non-invasive blood pressure measurements. These measurements are collected as part of the current standard of care, and therefore no additional patient monitoring devices are needed. We demonstrate the accuracy of the method in intensive care unit (ICU) patients, and show that it successfully generalizes to new unseen patients.

**Methods:** A deep convolutional neural network (CNN) was developed to predict the continuous arterial blood pressure waveform in a sliding window using a fixed number of seconds of electrocardiogram (ECG) and photo-plethysmographic (PPG) measurements per window, as well as other non-invasive blood pressure measurements as input. The Bland and Altman<sup>2</sup> method was used to evaluate the agreement between the gold standard invasive blood pressure measurements (the arterial catheter) and the predictions.

**Results:** Over 495,000 minutes of measurements from 568 ICU patients from the MIMIC Critical Care Database<sup>1</sup> were used to train the deep learning model to accurately predict the ABP waveform using signals recorded non-invasively in the ICU patients. In a set of 137 held-out patients used for validation, the deep neural network successfully predicts the continuous blood pressure waveform, with an accuracy and precision of  $2.9 \pm 10.5$  mmHg for systolic blood pressure and  $-0.3 \pm 6.3$  mmHg for diastolic blood pressure. The corresponding Bland-Altman plot is shown below.

**Conclusions:** A deep learning model can accurately predict the continuous arterial blood pressure waveform in ICU patients using data obtained non-invasively in all patients as part of the current standard-of-care.

## References:

1. Johnson, A. E. W. *et al.* MIMIC-III, a freely accessible critical care database. *Sci. Data* **3**, 160035 (2016).
2. Martin Bland, J. & Altman, Douglas G. STATISTICAL METHODS FOR ASSESSING AGREEMENT BETWEEN TWO METHODS OF CLINICAL MEASUREMENT. *The Lancet* **327**, 307–310 (1986).

