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The Exponential-Linear Function is Best for Parameterizing the Brachial Artery Compliance Curve of an Oscillogram Model

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***Abstract*—Parametric functions of the brachial artery compliance curve of an oscillogram model were compared using extensive patient data. The exponential-linear function was found to be the best amongst eight functions in terms of accuracy and convenience.**

***Clinical Relevance*—The parametric model of the oscillogram identified here can help improve the accuracy of automatic cuff BP measurement and thus cardiovascular risk stratification.**

I. Introduction

Most automatic cuff blood pressure (BP) measurement devices are based on oscillometry. These devices vary the external pressure of the artery via cuff inflation/deflation while measuring the cuff pressure. Systolic and diastolic BP (P_s and P_d) are estimated from the oscillogram, i.e., the function relating the amplitude of the cuff pressure oscillations (ΔO, which indicate blood volume pulsations) to the applied cuff pressure (P_c). A mathematical model of the oscillogram can help improve BP estimation. A parametric model may be fitted to the oscillogram to estimate BP in a principled and general way [1]. An effective model of the oscillogram is $\Delta O = k\, f(P_s\text{-}P_d)\text{-}k\, f(P_s\text{-}P_d)$, where $f(\cdot)$ is the arterial blood volume-transmural pressure relationship and k is a scale factor to map blood volume oscillations to cuff pressure oscillations. The derivative of $f(\cdot)$ with respect to P_c [$g(\cdot)$] represents the brachial artery compliance curve. This curve must be parametrized to be able to fit the model to the oscillogram. However, the best parametric function is unknown. Here, eight parametric functions were compared for representing the brachial artery compliance curve.

II. Methods

De-identified data collected from 147 human subjects at the Taipei Veterans General Hospital (Taiwan) were studied. Of those, 128 were cardiac catheterization patients and the other 19 were healthy subjects. The reference BP and cuff pressure waveforms were simultaneously recorded at 250 Hz. The cuff pressure waveforms were visually screened, and those with substantial artifacts or incomplete oscillograms were excluded. The oscillograms were first extracted from the cuff pressure waveforms. The model was then optimally fitted to the oscillograms in the least squares sense using eight different parametric functions for $g(\cdot)$. One of the functions studied, is the Exponential linear (EL) curve, defined as follows -

$$g(P)=d\cdot e^{\frac{P - a}{b}}u(-P + a) + d\cdot e^{\frac{-(P - a)}{c}}u(P - a) \quad (1)$$

The measured systolic and diastolic BP were inputted for P_s and P_d in the model. Four unknown parameters remained representing the peak position of the brachial artery compliance curve (a), the left and right curve widths around the peak position (b & c), and the curve amplitude (d). The model fits were evaluated in terms of the root-mean-square (RMS) of the fitting error normalized by the RMS of the measured oscillogram (NRMSE). A one-way repeated measures ANOVA was performed to determine any significant differences between the model fits.

III. Results

The Weibull (WB) and EL parametric functions best fit the oscillograms with NRMSEs of $8.2 \pm 0.3\%$ (mean ± SE) and $8.7 \pm 0.3\%$. ANOVA showed that the model fits were different overall ($p < 0.05$). The above-mentioned functions predicted the data significantly better than three of the other functions (Burr3, Burr12 & Fisk [1]) and the Drzewiecki function [2]. The remaining two functions were Gaussian (GS) and exponential (EX) functions [3], and their fits were not statistically different from the WB and EL functions.

IV. Discussion & Conclusion

The WB and EL functions produced the best oscillogram fits of the eight functions studied and fit similarly across age, gender, and BP levels ($p > 0.05$). The WB function performed marginally better than the EL function. However, this function has a complex relationship between its parameters and the key compliance curve characteristics. The EL function (Eq.1), on the contrary, fits the experimental data almost as well, and its parameters (a, b, c, and d) correspond directly to the peak location, left and right curve widths, and peak amplitude of the compliance curve. Further, unlike the GS and EX functions, it leads to simple closed-form expressions. Hence, the EL function is best for parametrizing the brachial artery compliance curve of an oscillogram model.

References

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