Mathematical Modeling of Oscillometric Blood Pressure Measurement: A Complete, Reduced Oscillogram Model


Abstract—The most suitable parametric function for defining the brachial artery compliance curve in a reduced model of the oscillogram is unknown. A three-parameter exponential-linear function was identified via analysis of extensive patient data.

Clinical Relevance—The complete, reduced oscillogram model can advance popular oscillometric BP measurement.

I. INTRODUCTION

Recent years have seen oscillometry emerge as perhaps the most important blood pressure (BP) measurement principle. Oscillometric devices measure blood volume oscillations as a function of the external pressure of an artery and compute BP from therein. Mathematical modeling of the oscillogram is useful for understanding and advancing oscillometric BP measurement. An effective, reduced model of the oscillogram relating cuff pressure oscillation amplitude (ΔO) to external cuff pressure of the artery (Pc) is: ΔO(Pc) = k ∫Pd–Pe g(P)dP, where g(·) is the arterial compliance curve, Pd and Pc are systolic and diastolic BP, and k relates blood volume to cuff pressure oscillations [1]. Several parametric functions have previously been proposed to define g(P) and thereby evaluate or improve oscillometric BP computation algorithms. However, the best parametric function has yet to be determined. In this study, several prospective parametric functions of g(P) were compared in terms of model fitting to oscillogram measurements.

II. METHODS

The study data comprised oscillometric arm cuff pressure waveforms and mainly invasive brachial BP from 122 patients covering a 20–120 mmHg pulse pressure range. Eight prospective, three-parameter functions of the brachial artery compliance curve were identified including five published ones. The oscillogram measurements were constructed from the cuff pressure waveforms. Reduced oscillogram models, inputted with systolic and diastolic BP values and each function, were optimally fitted to the oscillogram measurements in the least squares sense. The model fits for the eight functions were assessed for different cuff pressure ranges and subgroups (e.g., male and female) via the normalized root-mean-squared-error (NRMSE).

III. RESULTS

An asymmetric exponential-linear (EL) function for defining g(P) [1] yielded as good or better model fits compared to the other seven functions (via one-way repeated measures ANOVA). This EL function [1] is given as follows:

\[ g(P) = d \cdot e^{\frac{P}{b}} \cdot u(-P) + d \cdot e^{\frac{-P}{c}} \cdot u(P) \]

where d denotes the peak amplitude of the curve, b and c denote the negative and positive transmural pressure curve widths, and u(·) is the unit-step function. The EL function yielded an NRMSE of 9.2 ± 0.3% (mean±SE) in fitting the full oscillogram measurements. This function produced NRMSEs of 7.9±0.3 and 5.1±0.2% in fitting the tail-trimmed (flat tails removed) and lower half-trimmed (<50% of ΔOmax removed) oscillogram measurements, respectively. The EL function also resulted in NRMSEs from 6.5±0.5 to 8.5±0.3% in fitting the tail-trimmed oscillogram measurements for the subgroups of <60 and ≥60 years, male and female, <60 and ≥60 mmHg pulse pressure, and baseline and nitroglycerin.

IV. DISCUSSION & CONCLUSION

The findings may not have been expected. The Drzewiecki [2] and asymmetric exponential [1] functions have been used the most to define g(P) but did not fare as well as the EL function. Amongst the eight prospective functions, the EL function also stood out in terms of mathematical convenience. The EL function is integrable and differentiable, which are ideal for closed-form expressions and fast model fitting, unlike asymmetric Gaussian [1] and exponential functions. Its parameters also have one-to-one correspondence with the compliance curve amplitude and widths in contrast to the Drzewiecki function. For example, only the average estimates of the parameter c in the EL function increased significantly after nitroglycerin administration, in line with the expected vasodilatory effect of the drug. Overall, the EL function is the most suitable for the reduced oscillogram model.

REFERENCES


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