ABSTRACT

Advances in Oscillometric Blood Pressure Measurement

By

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High blood pressure (BP) is a major cardiovascular risk factor that is treatable, yet hypertension awareness and control rates are low. Ubiquitous BP monitoring technology could improve hypertension management, but existing devices require an inflatable cuff and are not compatible with such anytime, anywhere measurement of BP. Oscillometry is the blood pressure (BP) measurement principle of most automatic cuff devices. We extended the oscillometric principle, which is used by most automatic cuff devices, to develop a couple of instruments to measure cuff-less BP using a smartphone-based device and standalone iPhone application. As the user presses her/his finger against the smartphone, the external pressure of the under lying artery is steadily increased while the phone measures the applied pressure and resulting variable amplitude blood volume oscillations. A smartphone application provides visual feedback to guide the amount of pressure applied over time via the finger pressing and computes systolic and diastolic BP from the measurements.

We prospectively tested the smartphone-based device for real-time BP monitoring in human subjects to evaluate usability (n = 30) and accuracy against a standard automatic cuff-based device (n = 32). We likewise tested a finger cuff device, which uses the volume-clamp method of BP detection. About 90% of the users learned the finger actuation required by the smartphone-based device after one or two practice trials. The device yielded bias and precision errors of 3.3 and 8.8 mmHg for systolic BP and −5.6 and 7.7 mmHg for diastolic BP over a 40 to 50 mmHg range of BP. These errors were comparable to the finger cuff device. Cuff-less and calibration-free monitoring of systolic and diastolic BP may be feasible via a smartphone. In addition, we tested the iPhone application. The application yielded bias and precision errors of −4.0 and 11.4 mmHg for systolic BP and −9.4 and 9.7 mmHg for diastolic BP (n = 18). These errors were near the finger cuff device errors. This proof-of-concept study surprisingly indicates that cuff-less and calibration-free BP monitoring may be feasible with many existing and forthcoming smartphones.
These devices use empirical algorithms, already described in the literature, to estimate blood pressure. Hence, the next objective was to establish formulas to explain three popular empirical algorithms – the maximum amplitude, derivative, and fixed ratio algorithms. A mathematical model of the oscillogram was developed and analyzed to derive parametric formulas for explaining each algorithm. Exemplary parameter values were obtained by fitting the model to measured oscillograms. The model and formulas were validated by showing that their predictions correspond to measurements.

The formula for the maximum amplitude algorithm indicates that it yields a weighted average of systolic and diastolic BP (0.45 and 0.55 weighting) instead of commonly assumed mean BP. The formulas for the derivative algorithm indicate that it can accurately estimate systolic and diastolic BP (<1.5 mmHg error), if oscillogram measurement noise can be obviated. The formulas for the fixed ratio algorithm indicate that it can yield inaccurate BP estimates, because the ratios change substantially (over a 0.5-0.6 range) with arterial compliance and pulse pressure and error in the assumed ratio translates to BP error via large amplification (>40). The established formulas allow for easy and complete interpretation of perhaps the three most popular oscillometric BP estimation algorithms in the literature while providing new insights. The model and formulas may also be of some value towards improving the accuracy of automatic cuff BP measurement devices.