Development of an Electronic Rapid Arterial Stiffness Meter

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Abstract: Among the risk factors for cardiovascular disease (CVD), increased density or stiffness of the arterial wall occupies an important place. World studies have shown that stiffness of arteries leads to the development of hypertension and atherosclerosis. The gold standard for measuring this parameter is the pulse wave velocity, but the classical measurement scheme is inconvenient for a mass population survey. Therefore, attempts to simplify this procedure do not stop. The task was to develop a miniature auxiliary unit for household tonometers with the standard procedure for measuring blood pressure using the oscillometric method. According to the developed algorithm, the properties of the pressure oscillogram in the measuring cuff are determined. In the case of a borderline and pathological signal, the patient is referred to a cardiologist for further examination.

Keywords: arterial stiffness, risk factors for cardiovascular diseases, general medical examination, rapid diagnosis of early stages of atherosclerosis, electronic device for arterial stiffness measurement.

Introduction

The increased stiffness of the human vascular system primary arteries increases the systolic blood pressure (SBP) and decreases the diastolic (DBP) one. The pulse pressure and, simultaneously, the pulse wave velocity grow. This increases the pulse wave damaging impact on the blood vessels in the brain, heart and other inner parts causing their early deterioration.

Given the mentioned, the arterial stiffness and central pressure evaluation is essential for identification of high-risk individuals during examination of the patients suffering from cardiovascular diseases [8,4,7,6]. The effective arterial hypertension guidelines attribute the highest complication risks to increased pulse pressure (being a direct consequence of increased aortic stiffness) and pulse wave velocity (PWV) [9]. The traditional approach to PWV assessment implies recording the carotid and femoral artery pulse with pulse transducers and a high-rate (upwards of 100 mm/sec) pulse recorder.

Such state-of-the-art digital instruments as Complior (France) or Arteriograph (Hungary) use microchips to calculate the velocity. Instruments of this kind are considerably expensive whereas the examination procedure is cumbersome and inconvenient for the patient (the test procedure requires the patient to keep motionless in supine position with transducers being attached to the patient's carotid artery and pelvic area).

All that accounts for everlasting attempts to find more favorable and cost-efficient ways to estimate the arterial wall stiffness.

Methods and Materials

The research objective consisted in developing of an algorithm which would enable definition of arterial stiffness and cushioning efficiency by analyzing the home-use blood pressure monitor air tube pressure oscillation curve under the standard measurement procedure.The principal measurement methods use analysis of the arterial oscillogram waveform which represents the records of the cuff pressure oscillations acquired during a gradual cuff pressure deflation procedure (*Fig. 1*).

Early solutions involving the mentioned algorithm can be illustrated by the instruments suggested by the Japanese authors H. Komine [6] and I. Kozuhiro [7] which virtually constitute a modification of an inexpensive and widely used automatic pressure monitor for home use.

Judging from the publications, the algorithm used by both devices is based on the discovered oscillometric envelope slope discrepancies between the young individuals and the elderly patients with sclerotic arterial changes (*Fig. 2*).

In our opinion implementation of an easily affordable medical instrument can be considered a significant achievement. There are certain doubts, however, concerning usage of the oscillogram envelope slope, a tangential to which is prone to variability (*Fig. 3*).

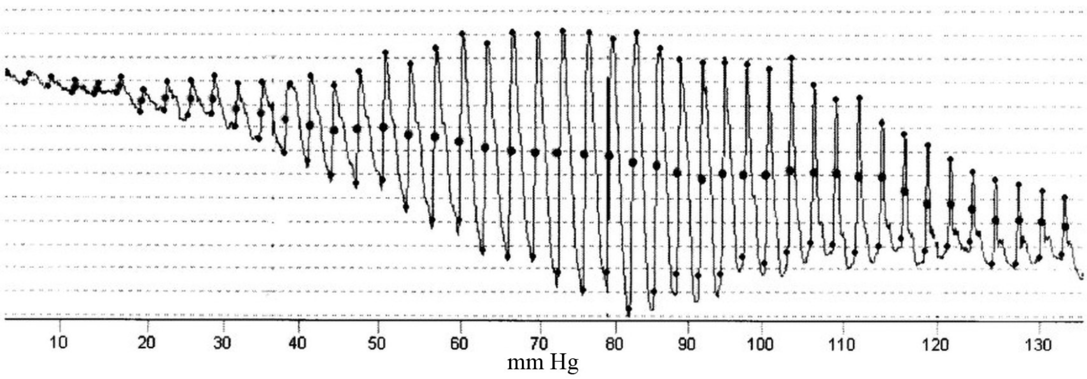

Figure 1. Arterial oscillogram (compression cuff pressure oscillation waveform) acquired during arterial pressure (AP) testing with an automatic monitor upper-arm cuff

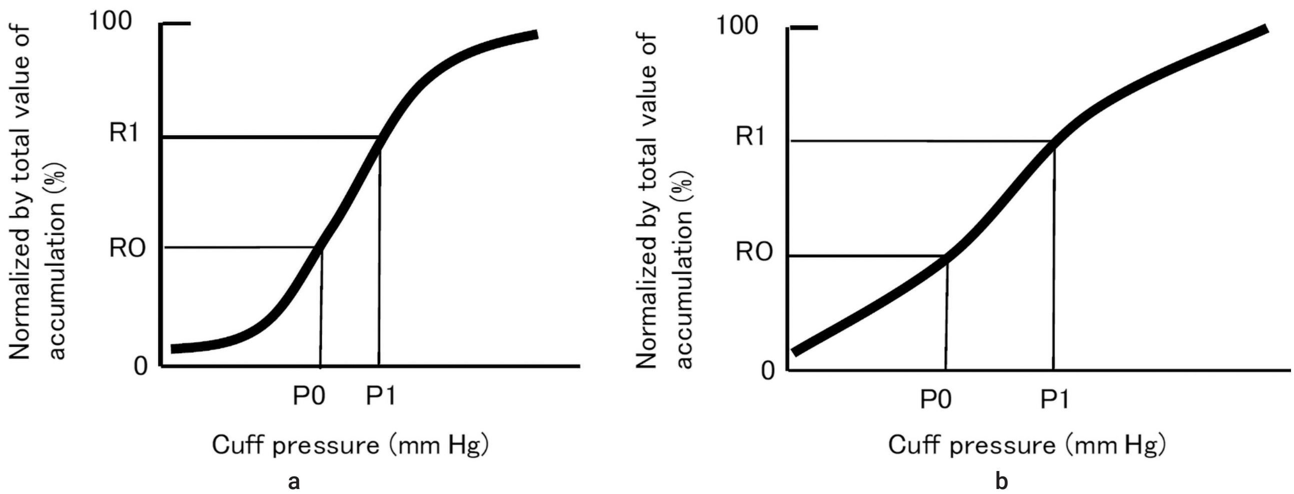

Figure 2. Arterial oscillogram envelope slope for younger (A) and elderly (B) individuals obtained for upwards of 200 subjects

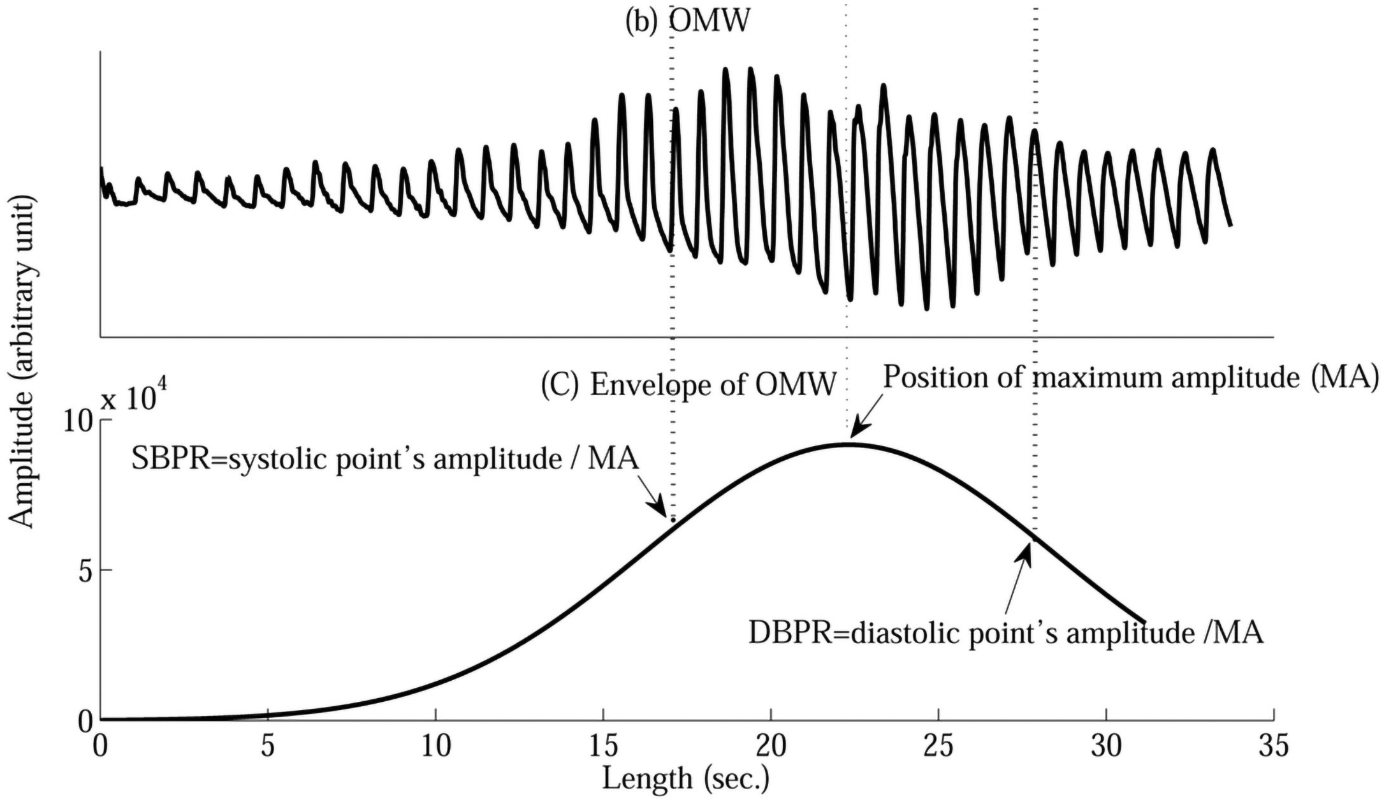

Figure 3. **Oscillometric waveform envelope illustration offered in Stefanadis C. et al., 2000** [8]

Alternatively to the examples above, the blood vessel stiffness measurement method suggested in this research is based on everyday experience of operating automatic pressure monitors. It was noticed that as the cuff pressure is being reduced the screen heartbeat indicator (usually displayed as a heart-shaped ideograph) appears considerably earlier during the examination of the elderly individuals than it is the case with the younger ones, the arterial pressure level being, interestingly, comparable.

For the primary observation data verification the discovered tendency underwent a preliminary study involving two groups of subjects: that with the average age of 25 years (12 persons) and that with the average age of 58 years (15 persons). The average delay required for the heartbeat indicator to appear reached 35 ± 3 mm Hg among the first group and did not exceed 15 ± 2 mm Hg in the second group (the difference is statistically valid).

Apparently, the mechanism underlying the mentioned phenomenon is similar to that described by the Japanese authors: the arterial vessel (in this case brachial artery) stiffness facilitates early transmission of heartbeat impulses through the compression cuff before the artery is opened and blood flow resumes and these false pulsewaves become detected by the pressure monitor sensor.

The described process can be visualized with oscillometric waveforms taken from two subjects: the one with normal vascular wall elasticity and the one with increased stiffness caused by age-related or sclerotic processes in the arterial walls (*Fig. 4 and 5*).

It is noteworthy that the brachial pulse data proved to be much closer to the systemic circulation parameters than those yielded by finger artery monitoring. This finding is supported by years of research which considers brachial arterial pressure an indicator of the systemic one and the widespread use of such endothelial-dependent vasodilatory function evaluation method, as Celermajer test, which implies extrapolating the results of the brachial artery responsiveness ultrasound assessment to make judgements on the state of the overall system vascular reserve [1].

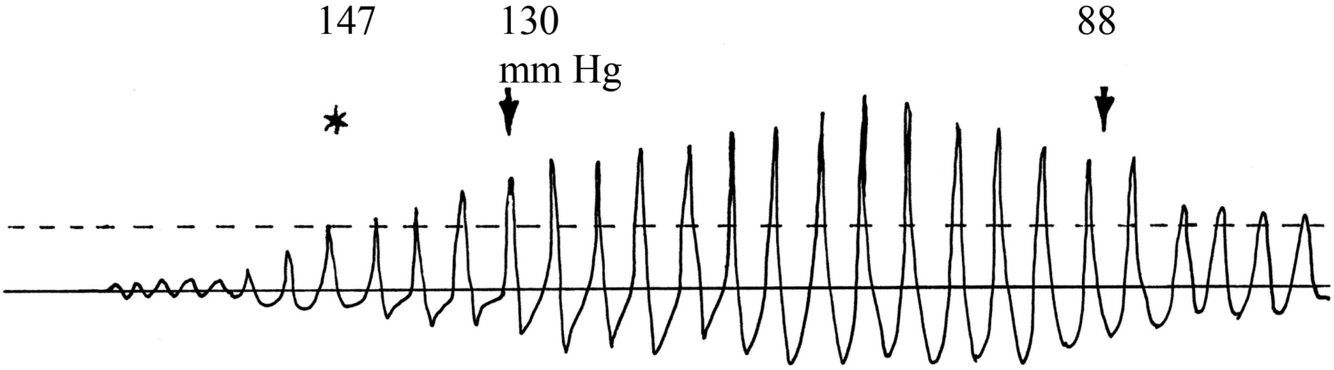

Figure 4. **Illustration of an arterial waveform for a subject with normal arterial wall stiffness.**
The dashed line marks the heartbeat transducer actuation threshold. The AP level corresponding to the indicator appearance is marked with an asterix, the arrows showing the the systolic and diastolic AP levels. For this example the difference between the heartbeat indication appearance and the systolic AP value amounts to 17 mm Hg.

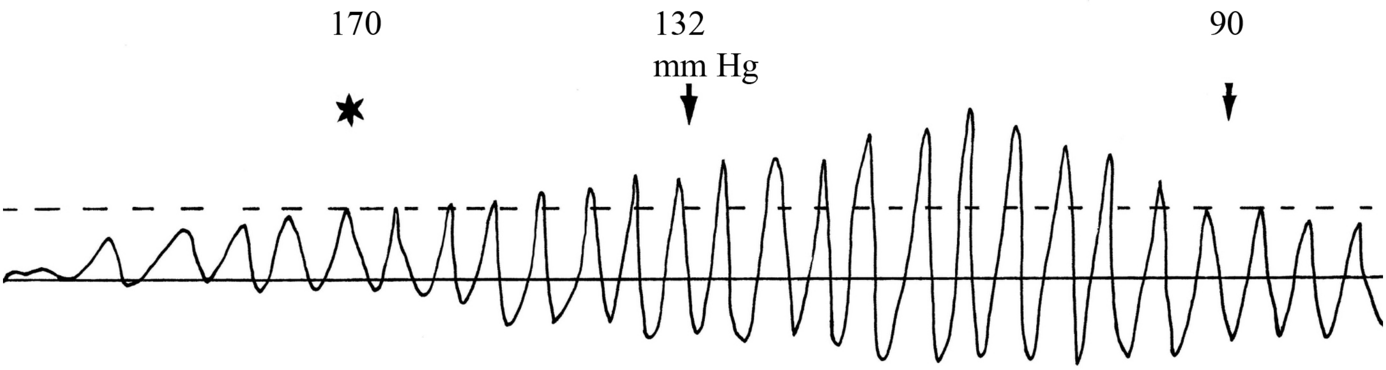

Figure 5. **Arterial waveform for the subject with increased arterial wall stiffness.**
The difference between the heartbeat indication appearance and the systolic AP level amounts to 38 mm Hg.

Results

The algorithm reliability was tested by evaluating the precision of the suggested algorithm and the data yielded for the same subjects by the classical pulsewave velocity evaluation method (by the delay between the aortic pulse detection and the femoral pulse detection).

The study covered 107 subjects aged from 19 to 65 and included both virtually healthy individuals and those with the onset of arterial hypertension and coronary heart disease. The healthy group consisting of the individuals without cardiovascular pathology onset numbered 31 persons (16 males and 15 females with the average age being 25.3 years).The comparison group consisted of 42 subjects of middle age (22 males and 20 females with the average age being 47.8 years) featuring no cardiovascular disease manifestation and performing moderate physical activity (Nordic pole walking classes in fitness centers). The cardiovascular pathology group consisted of 34 individuals (17 males and 17 females with the average age being 56.1 years) and included patients suffering from stage 1–2 arterial hypertension or coronary heart disease without previous myocardial infarction. The rheograph used for examination was produced by *Mitsar* LLC (Saint-Petersburg). The correlation coefficient was 0.79 which is sufficient to justify distribution of subjects among risk groups.

The average pulse wave velocity registered in the group of healthy subject was 5.6 m/sec. That for the comparison group was 6.7 m/sec and reached 12.1 m/sec in the group of cardiovascular pathology patients.

Analysis of these data demonstrates that the pulse wave velocity value discrepancy between the control group and the comparison group was not extremely significant ($p > 0.05$) whereas its difference from the pathology group was statistically valid ($p > 0.001$).

Bearing the above mentioned in mind we developed a preliminary roadmap for designing and production of a automated instrument capable of both measuring the AP and evaluating the arterial stiffness. Figure 6 demonstrates the mockup of the suggested instrument.

Conclusion

The obtained preliminary clinic data enable us to proceed to practical implementation of the design of an inexpensive and easy-to-operate arterial stiffness rapid meter designed as a miniature auxiliary unit to a regular blood pressure monitor for home use. The following stages of the instrument production are suggested: 1. Building a mockup blood pressure monitor supporting an additional option. 2. Primary clinic research for algorithm elaboration. 3. Developing a trial prototype. 4. Extended clinic study in a large clinic.

Figure 6. **First version mockup of the arterial stiffness rapid meter**

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