A wrist cuff method for acquisition and analysis of radial artery waveforms used for blood pressure measuring

Jiri Jilek[1], Milan Stork[2]
[1] King-Drew Medical Center, Los Angeles,
California, USA
[2] Department of Applied Electronics and Telecommunications
University of West Bohemia, Plzen, Czech Republic
E-mail : jilekj@usa.net, stork@kae.zcu.cz

Abstract:
Noninvasive assessment of arterial waveform contours and waveform reflections have received increased attention in recent years. The prevalent method is acquisition of radial waveforms by applanation tonometry. The disadvantage of tonometry is that a skilled application of the tonometer probe is required. The authors developed an experimental system that automatically acquires radial artery waveforms from a wrist cuff. Application of the wrist cuff does not require a special skill. The system and the method of waveform acquisition from the wrist cuff are described and representative waveforms are introduced.

INTRODUCTION

Over the last decade, there has been increased interest in arterial mechanical properties [1] with appreciation of the importance of wave reflections in ageing and in hypertension [2]. Systolic augmentation of pressure in the ascending aorta caused by early wave reflections is described by aortic augmentation index (AI) [3]. AI is one of a number of inter-related parameters reflecting vascular stiffness that have been associated with increased cardiovascular risk. Since direct measurement of aortic pressure is invasive, non-invasive methods of derivation of similar data by applanation tonometry have been developed and resulting waveforms have been described [4]. Carotid artery waveforms are the closest in distance and in shape to the aortic waveforms. Obtaining correct carotid waveforms does, however, require skilled application of the tonometer. Radial artery is often proposed as the preferred site for tonometry. Radial artery waveforms are, however, different from the waveforms of the ascending aorta. Manipulation of the radial waveforms is required for adequate approximation of the central aortic waveforms. Arterial transfer function has been used for these purposes and at least one commercial system using applanation tonometry has been developed. Skilled application of the pencil-shaped tonometer is necessary in order to acquire correct waveforms. Errors resulting from incorrect application of the tonometer have been reported [5]. Several studies compared transfer function methods with direct measurements and one study [6] concluded that transfer function may not be necessary and that a simple, linear relationship between the radial and the aortic waveforms may be sufficient to define augmentation index. The authors developed an experimental system that uses a commercial blood pressure wrist cuff to obtain radial artery waveforms. Waveforms acquired with the system were compared with published waveforms in order to determine if wrist cuff waveforms could be used in a manner similar to the waveforms acquired by tonometry.

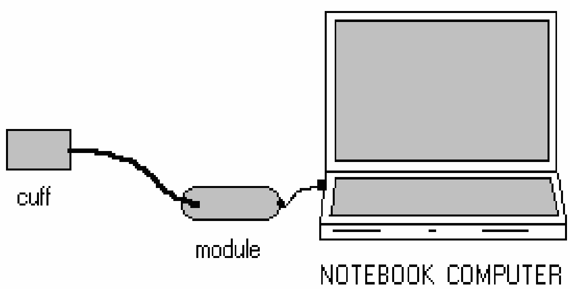

Figure 1. The system for acquisition of wrist cuff radial artery waveforms.

METHODS

The system (Figure 1) for acquisition of wrist cuff waveforms consists of a notebook computer, a module with pneumatic and electronic circuits and a notebook computer with special software. The notebook controls all pneumatic and electronic functions of the system via USB interface.
Block diagram of the module (Figure 2) consists of a pneumatic circuit and an electronic circuit. The pneumatic circuit uses a miniature air pump to inflate the cuff, and a solenoid valve to deflate the cuff. Commercial wrist cuff (Omron, model 602) was used. The cuff has a small bladder and a stiff exterior fabric. This feature diminishes damping of higher frequencies and improves signal-to-noise ratio. Cuff pressure is converted into voltage by a piezoresistive pressure sensor. The sensor output is amplified by an instrumentation amplifier (Burr-Brown INA118), filtered and separated into 2 analog channels. Channel 1 represents cuff pressure (CP) and channel 2 represents radial artery pressure waveforms (PW). The 2 analog signals are digitized by a 12-bit AD converter and transmitted to the notebook via USB interface. Sampling rate is 85 samples/sec. The controller provides 2 digital lines that control the air

pump and the solenoid valve. Notebook software controls cuff inflation and deflation, acquisition and display of wrist cuff waveforms, and waveform storage and retrieval. Acquired waveforms can be analysed manually with a cursor that can move in increments as small as 11.8 milliseconds (the sampling rate). Cuff pressure and waveform pressure are displayed after each cursor step.

Cuff inflation pressure is entered manually. Best waveforms are obtained with the cuff inflated to the pressure just below the expected diastolic pressure (DBP). At lower cuff pressures, the waveform amplitudes are smaller and signal-to-noise ratio is decreased. At low cuff pressure, the waveforms can be altered by pressure in smaller arteries. At cuff pressures higher than DBP, the waveforms are distorted by partial occlusion of the radial artery.

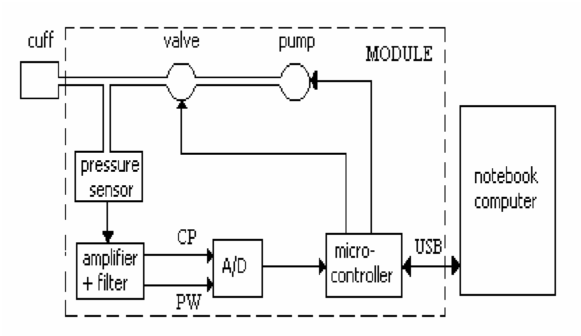

Figure 2. Block diagram of the system's module

Wrist cuff radial waveforms were acquired from 4 volunteers younger than 35 years, 4 volunteers between 35 and 60 years, and 4 volunteers older than 60 years. All data were acquired with the subjects in sitting position. Data acquisition procedure started with an automatic cuff inflation to the pressure approximately 5 mmHg below the diastolic blood pressure. When cuff pressure reached the desired level, the pump was automatically turned off and a 10 second data acquisition started. At the end of 10 sec interval the cuff was deflated and the waveforms were displayed. Waveforms free of artifacts and arrhythmias were accepted and stored.

After completion of data acquisition, the waveforms were analyzed and several variables were computed: heart rate (HR) was computed from time intervals between successive waveforms, upstroke time (UT) was computed as time in milliseconds from the foot to the peak of a waveform, and amplitude (AMPL) was computed from the the waveform foot to the peak and expressed in pascals. Means of 3 variables were computed.

RESULTS

The computed wrist cuff waveform variables are in the Table. HRs could not be matched exactly. The reason for matching for HR is that UT has a tendency to shorten with HR acceleration.

Waveform amplitudes (AMPL) increased by 15% from age <30 to age 35 -60 and 49% from age <30 to age >60. Upstroke time (UT) increased 30% from age <30 to age 35-60 and 59% from age <30 to age >60.

Table. Mean values of variables HR, AMPL, UT computed for 3 age groups.

Age	HR [bpm]	AMPL [pasc]	UT [mSec]
< 30	69	594	102
35 – 60	72	735	134
> 60	66	1197	162

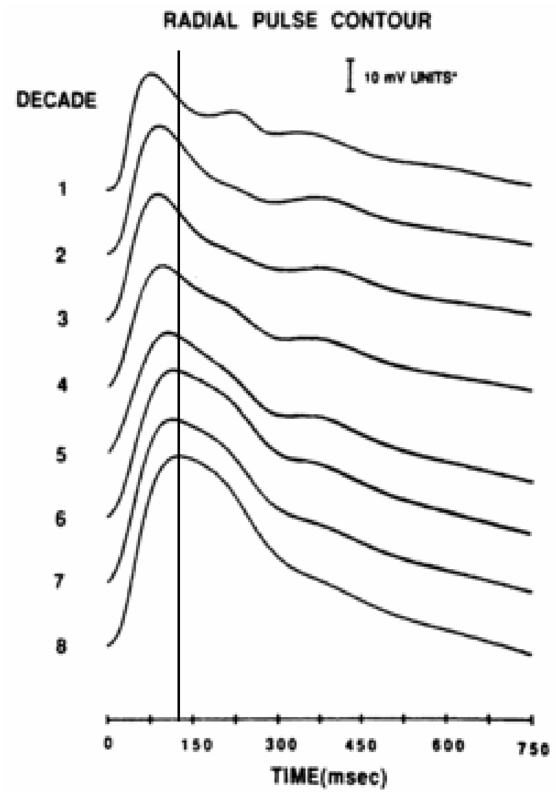

Figure 3. Averaged tonometric radial waveforms from ages 10 to 80 (decade 1 – 8). The solid vertical line uses the peak of decade 8 waveform as timing reference.

DISCUSSION

The values of computed variables from the Table show similar chronological changes to those observed in studies using radial tonometry [7]. Increases in amplitudes are attributed to decreased arterial compliance and increases in upstroke time are caused by the combined effects of decreased arterial compliance [8] and arterial wave reflections [7].

The waveforms in Figure 3 were obtained by applanationn tonometry and waveforms in Figure 4 were acquired from wrist cuff. The waveforms from Fig 3 and the waveforms from Fig 4 show similar changes with age. Waveforms obtained from radial arteries of young subjects have shorter UT because the heart ejects its stroke volume faster into compliant arteries [8]. Young subject's arteries have much more pronounced dicrotic notch (a small waveform on the descending part of the radial waveform). In middle age the dicrotic notch is diminished and in old age it is almost completely obliterated. Such age-dependent waveform alterations are considered to be of structural origin and they do not change substantially with blood pressure or with heart rate.

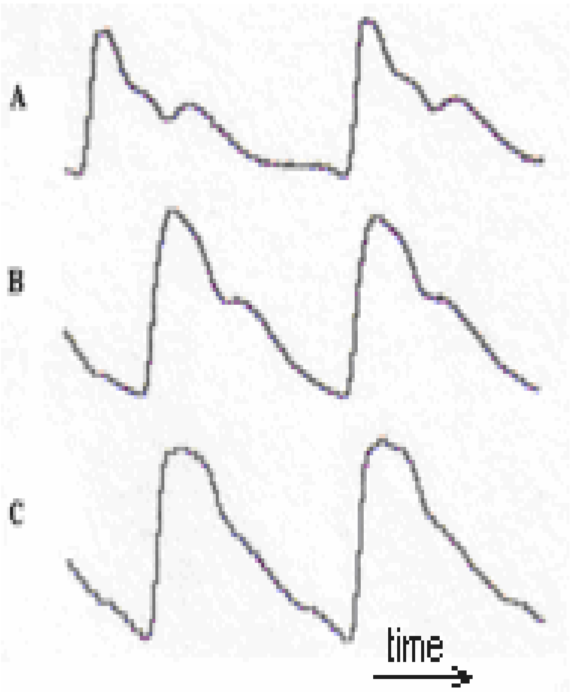

Figure 4. Age related waveforms obtained from wrist cuff. (a) 22 years old female, (b) 51 years-old male, (c) 70 years old female.

An important application of radial pressure waveforms is the determination of aortic AI. AI is usually calculated as the ratio of aortic augmentation pressure and overall aortic pressure. Aortic AI is highly predictive of cardiovascular mortality [9]. Increased aortic AI increases the load presented to the left ventricle. The brachial or radial arterial pressures do not represent the load accurately. Application of a transfer function allows the determination of aortic AI and facilitates synthesis of the aortic pressure waveform. Accuracy of the transfer function depends on high frequency information. The transfer function shows inter-subject variability of aortic AI and its accuracy has been questioned. A recent report [6] showed that aortic AI can be derived from the radial waveform without use of a mathematical transfer function. Such approach is suitable for waveforms acquired by the wrist cuff method because the air in the wrist cuff is likely to dampen high frequencies. Computation of aortic AI from the wrist cuff waveforms is currently under investigation. Another potential application of wrist cuff method is computation of "oscillatory" arterial compliance [10]. Oscillatory compliance reflects changes affecting central aortic pressure.

Wrist cuff radial waveforms contain information that reaches beyond variables determined in this study. An experimental system for the determination of blood pressures and hemodynamics from wrist cuff oscillometric waveforms has been developed by the authors and described previously [11, 12].

CONCLUSION

The preva¬lence of high blood pressure increases dramati¬cally with age, such that the lifetime risk of high blood pressure approaches 100% [13-20]. Despite the availability of effective antihypertensive agents, rates of hypertension treatment and control have remained low and static over the last decade. Control of blood pressure begins with accurate measurement leading to appropriate diagnosis and treatment decisions.

Radial arterial waveforms obtained with the wrist cuff method are similar to those obtained with radial tonometry. Wrist cuff method has the advantage of automatic data acquisition where trained observer is not required as is the case with radial tonometry.

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