CHARACTERIZATION OF THE STATISTICAL VARIABILITY OF SYSTOLIC AND DIASTOLIC BLOOD PRESSURE

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ABSTRACT

Blood pressure is subject to significant physiological variability over time. The fluctuation of systolic and diastolic values (SBP and DBP) could lead to unrepresentative readings if not taken into consideration. This paper presents a statistical study of this variability and focuses on its main frequency components using continuous recordings of the arterial pulse waveform in healthy subjects and in ICU patients. Results show that very low frequencies between 0.025 and 0.05 Hz, low frequencies between 0.05 and 0.15 Hz, and high frequencies between 0.15 and 0.5 Hz are all important contributors to the variability. Moreover, the standard deviation of SBP and DBP values, combined with device errors, could result in readings that are associated with an unacceptable level of measurement uncertainty.

INTRODUCTION

Systolic and Diastolic blood pressure are subject to significant continuous changes over different time scales. However, the beat-to-beat blood pressure (BP) variability has not been widely investigated [1] even though it could strongly affect the accuracy of BP measurements and impact clinical management.

Noninvasive automatic measurement of systolic and diastolic blood pressure (SBP and DBP) is widely used in a broad variety of clinical settings and in home health monitoring. According to the ANSI\AAM SP10 I standard, the accepted accuracy of a commercially approved device is ±5 mmHg relative to reference readings by a trained observer [2]. However, the relevance of this measure of accuracy is questionable given that BP can vary by as much as 20 mmHg over several seconds [3] and more over longer durations. Moreover, given this variation, a single reading taken at the doctor's office is likely not sufficient for the determination or adjustment of medication dosage.

BP variability can be studied over various time scales ranging from seconds to years [e.g. 1, 3]. It can also be investigated using intermittent measurements or be extracted from continuous recordings of the arterial pulse waveform. When the arterial pulse waveform is available, the oscillations in BP have been divided into three main frequency ranges: the very low frequency (VLF) range from 0.025 to 0.05 Hz, the low frequency (LF) range between 0.05 and 0.15 Hz associated with vascular tone changes and so-called Mayer waves, and the high frequency (HF) range between 0.15 and 0.5 Hz associated with the respiratory pattern and intrathoracic pressure changes [4, 5]. The goal of this study is to quantify the statistical characteristics of SBP and DBP variability, and estimate the contributions of the different frequency ranges (VLF, LF, HF) to this variability.

METHODS

Subjects and Measurements

The analysis was done on data obtained from the PhysioNet online database [6]. Twenty samples were studied; ten samples were calibrated intra-arterial BP recordings taken from patients in the intensive care units (MGH/MF Waveform Database), and ten samples were photoplythesmographic recordings of BP waveforms in young healthy subjects (Fantasia Database) measured using Finometer® PRO (Finapres Medical System, FMS©, Amsterdam, The Netherlands). The waveforms obtained from healthy subjects in the Fantasia database are uncalibrated. In order to allow comparison with data from the MGH/MF database, we assumed a mean SBP of 120 mmHg for all samples in this database. Eight out of ten signals of the MGH/MF recordings had a length of 160 ± 15.1 seconds (means±SD) whereas the other two were much shorter (58 ± 3.5 seconds). Similarly, seven out of ten signals from healthy subjects were 236±7.2 seconds long and three were 108±2.8 seconds.

The waveforms were analyzed using MATLAB and its statistical toolbox (The MathWorks Inc, Natick, MA, USA).

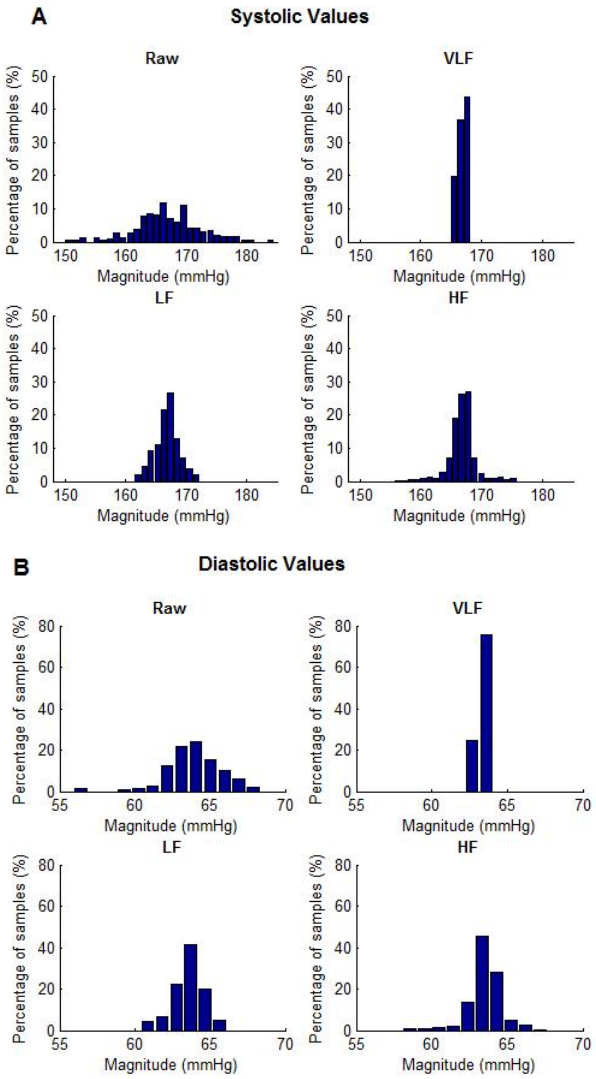

Figure 1. (A) Histogram of systolic blood pressure (SBP) values and (B) diastolic blood pressure (DBP) values for an ICU patient from the PhysioNet Database. The graphs show the respective histograms of the raw signal (top left), the very low frequencies (top right), low frequencies (bottom left) and high frequencies (bottom right).

Data Analysis

The main purpose of the analysis is to estimate the systolic (SBP) and diastolic (DBP) variability that results from BP fluctuations and to investigate the sources of this variability.

A peak detection algorithm allowed the identification of the peaks and troughs of the BP waveform, which correspond to the SBPs and DBPs respectively. Histograms of these values were constructed to characterize the distribution of the SBP and DBP, and the mean, standard deviation, skewness, and kurtosis were determined (Fig. 1). For the purpose of our study, we assumed that the signals are locally stationary.

In order to study the contribution of the VLF, LF, and HF frequency ranges to SBP and DBP variability, the peaks and troughs were interpolated to form evenly sampled waveforms at 60 Hz. Bandpass FIR filters (500 taps) were then used to isolate waveform components in each frequency range, and the histogram, mean, and standard deviation of each filtered waveform were then determined.

RESULTS

Analysis of the raw waveforms from the ICU patients in the MGH/MF database showed that the standard deviation ranged from 1.79 to 8.52 mmHg (mean SD ± SE: 5.39±0.77 mmHg) for the SBP and from 1.15 and 5.76 mmHg (mean SD ± SE: 3.50±0.46 mmHg) for the DBP (Table IA).

For healthy subjects in the Fantasia database, the standard deviation ranged from 3.02 to 7.07 mmHg (mean SD ± SE: 4.92±0.49 mmHg) for SBP and from 2.51 to 3.94 mmHg (mean SD ± SE: 3.39±0.17 mmHg) for DBP (Table IB).

Table 1: Average, standard deviation, skewness and kurtosis for the (A) ICU patients and (B) the healthy individuals. Values are means over subjects ± SE.

A

		Raw	VLF	LF	HF
Systolic Pressure	*Average*	146.45±12.07	146.44±12.08	146.51±12.06	146.45±12.08
	Standard Deviation	5.39±0.77	1.55±0.40	2.13±0.44	1.62±0.28
	Skewness	0.29 ±0.23	(-)0.25±0.14	0.19±0.11	0.097±0.058
	Kurtosis	4.04±0.69	3.67±0.58	3.51±0.48	4.79±0.65
Diastolic Pressure	*Average*	61.01±21.32	60.51±21.64	60.54±21.63	60.5±21.64
	Standard Deviation	3.5±0.46	1.16±0.17	1.72±0.32	1.24±0.24
	Skewness	(-)0.21±0.49	0.18±0.22	(-)0.049±0.08	(-)0.305±0.29
	Kurtosis	5.97±1.02	3.64±0.87	5.05±1.29	8.87±2.13

B

		Raw	VLF	LF	HF
Systolic Pressure	*Average*	119.99±0.023	120.04±0.05	119.99±0.026	119.99±0.023
	Standard Deviation	4.92±0.49	1.37±0.17	1.37±0.14	0.67±0.10
	Skewness	0.10±0.23	0.066±0.054	(-)0.025±0.14	(-)0.063±0.059
	Kurtosis	3.81±0.53	3.26±0.46	4.64±1.22	4.41±0.75
Diastolic Pressure	*Average*	53.84±4.16	53.87±4.16	53.84±4.16	53.84±4.16
	Standard Deviation	3.39±0.17	1.25±0.10	0.96±0.11	0.53±0.089
	Skewness	0.49±0.22	0.10±0.061	(-)0.0059±0.12	0.19±0.22
	Kurtosis	4.75±0.92	3.08±0.19	5.41±1.23	13.69±4.68

For the ICU patients in the MGH/MF database, the average contribution of the VLF range to the total variance (equivalent to total non d.c. power) over the frequency range of 0.025 – 0.5 Hz was 28.43% for the SBP and 21.33% for the DBP. The LF oscillations contributed on average 46.59% and 51.37% to the total variance of the SBP and DBP respectively, and the HF oscillations contributed 24.98% and 27.30% to the total variance of the SBP and DBP respectively (Fig. 2A). Moreover, the combined contribution of the three frequency ranges to the total variance in the raw signal was 43.40% and 63.82% for SBP and DBP respectively.

For the healthy subjects in the Fantasia database, the VLF range contributed on average 45.22% and 54.36% of the total variance for the SBP and DBP respectively. The LF oscillations contributed on average 43.45% and 34.17% for the SBP and DBP respectively, and the HF oscillations contributed 11.33% and 11.47% for the SBP and DBP respectively (Fig. 2B). The combined contribution of the three frequency ranges to the total variance in the raw signal was 17.97% and 25.85% for SBP and DBP respectively.

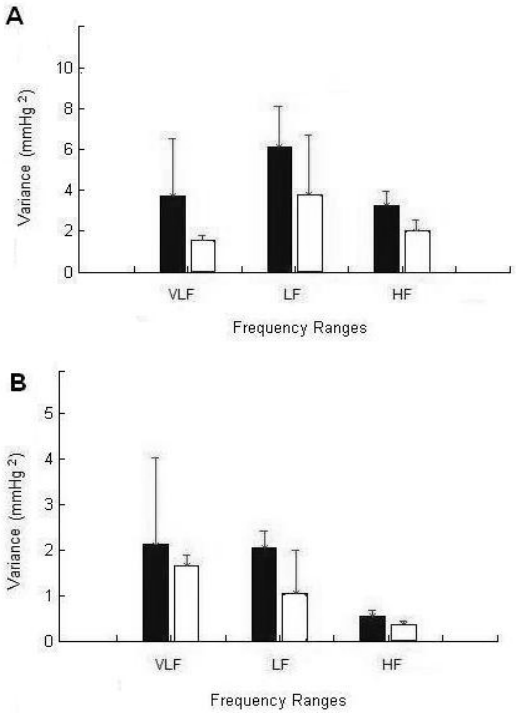

Figure 2. Contribution of the VLF, LF, and HF frequency regions to the variance of the blood pressure variations (A) ICU patients and (B) healthy subjects from the PhysioNet Database. The dark bars represent the SBP values, the white bars refer to the DBP values. The bars show mean variance over subjects ± SE.

CONCLUSIONS

Our study confirms previous observations that the beat-to-beat systolic and diastolic blood pressures undergo significant fluctuations over short periods, and quantifies the statistical characteristics of these variations. In some subjects, the standard deviation of SBP and DBP exceeded the maximum allowable error for BP measurement devices. Even in subjects for whom the standard deviation was less than 5 mmHg, the combination of intrinsic physiological variability and device error could produce measurements that are far from the average SBP and DBP in a given time period. As a result, this calls into question the reliability and utility of single BP readings taken at the doctor's office or at home. Our study also examined the contribution of VLF, LF, and HF oscillations to the variability in SBP and DBP. The results indicate that all three ranges are important contributors. This suggests that algorithms to suppress physiological oscillations, such as the respiratory or Mayer wave "artifact", in automatic BP measurement devices could reduce measurement uncertainty.

FUTURE WORK

Some measured SBP and DBP values may be considered as outliers. Future work will seek to identify the source of the detected outliers. If the source is physiological, the values will need to remain part of the measurement because of their potential diagnostic value. On the other hand, if the outliers are due to external factors (e.g. applied pressure, motion artifacts, or device error), it is important to remove them from the measurement or issue an alert. In addition, there is a significant contribution to the variability that originates outside the three studied frequency ranges. While some of this contribution may be due to drift in the signal, much of it may result from physiological variations at longer time scales (i.e. at frequencies lower than 0.025 Hz). Future work is needed to characterize this source of variability.

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