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Non Invasive Assessment of Carotid and Femoral Arterial Pressure using B-Mode Ultrasound Diameter Waveforms

Sebastian Graf, Damian Craiem and Ricardo L. Armentano

Abstract— **Non invasive local arterial blood pressure measurement has become a challenge over recent years. The aim of this study was to evaluate in a general population the validity of an alternative method to assess systolic local arterial blood pressure, from the analysis of B-mode diameter waveforms, and to estimate the accuracy when compared to carotid and femoral arterial tonometry. In 190 asymptomatic subjects (51±11 years, range: 24-73; pulse pressure: 51±11 mmHg, range: 31-93) systolic arterial pressure was obtained at the left carotid and left femoral artery by applanation tonometry (SBP_{Car}_Ton and SBP_{Fem}_Ton) and by automatic analysis of B-mode echographic images, calibrated using an iterative exponential model. Tonometry and echocardiography-derived pressure estimates correlated significantly (R=0.99, $p<0.05$). Mean difference between the two methods was only -2.5±5.0 mmHg for carotid artery (SBP_{Car}_Ton: 122±18 mHg), and -2.1±5.7 mmHg for femoral artery (SBP_{Fem}_Ton: 134±21 mmHg), independent of pressure level. In conclusion, alternative method was found to allow an accurate and precise estimation of systolic local arterial pressure, with an underestimation error of ~ 2%.**

I. Introduction

Non invasive local arterial blood pressure measurement has become a challenge over recent years. Although applanation tonometry allows the non-invasive recording of arterial pressure in both central and peripheral superficial arteries, it cannot be applied to all subjects (such as obese) and at all arterial sites [1]. Another possible approach to overcome this limitation is to derive pressure waveforms from arterial distension waves obtained from echographic images [1,2].

Using an echo-tracking system (radiofrequency tracking) for the assessment of arterial distension waves, and an appropriate calibration procedure, several studies demonstrated the validity of the procedure in assessing local pressure at the carotid artery [1,2,3,4]. A recent study involving 2026 subjects showed that systolic blood pressure derived from exponentially calibrated diameter curves underestimates pressures obtained by carotid tonometry by only 2% [4]. Arterial distension waves can be also obtained analyzing a sequence of echographic B-mode images with automatic image processing software [5,6]. This can be used in conventional ultrasound equipment, and consequently by more people. Therefore, the aim of this study was to evaluate in a general population the validity of an alternative method to assess systolic local arterial blood pressure, from the analysis of B-mode diameter waveforms, and to estimate the accuracy when compared to carotid and femoral arterial tonometry.

S.G. and D.C. are with CONICET, Argentina.
S.G., D.C. and R.L.A. are with the Favaloro University (Facultad de Ingeniería, Ciencias Exactas y Naturales), Buenos Aires, Argentina (corresponding author to phone: +54 11 4378 1150; fax: +54 11 4384 0782; e-mail: sgraf@ favaloro.edu.ar).

II. Material and Methods

A. Study subjects

Non invasive study was performed in 190 (114 men, 76 women) asymptomatic subjects ranging in age from 24 to 73 years old (mean 51±11 years). Measurements were performed after 15 min rest period in a temperature-controlled environment. In order to ensure similar haemodynamic conditions, for each arterial segment, echographic and applanation tonometry recordings were performed consecutively, with a separation time of about 2 minutes. Systolic (SBP_{bra}) and diastolic (DBP_{bra}) brachial blood pressure values were determined in the arm by sphygmomanometer procedure (supine position), between echographic and tonometer recordings. Hypertension was defined by blood pressure of 140 and/or 90 mmHg or above and/or presence of hypertensive medication.

Left carotid and left femoral arterial waveforms were assessed by experienced sonographer physicians with high-resolution B-mode echography (ATL HDI 5000, Miami Lakes, EE.UU) using a 7.5-MHz probe. Briefly, a sequence of B-mode images of at least 10 seconds were transferred to a computer, and digitized for offline analysis using an automated computerized system (Hemodyn4M®, Oxitech, Argentina). In order to obtain the diameter waveform, the sequences of images were analyzed automatically frame by frame. The anterior and posterior walls were detected. After analyzing the overall sequence, the software yielded as output, the internal diameter waveform, which was calculated as the difference between the far and near wall movement.

Arterial pressure waveforms were obtained at the left carotid and left femoral arteries (same site as the diameter waveforms) by applanation tonometry using a Miller pen-type tonometer (SPT 301, Millar Instruments, Houston, Texas, USA) and a dedicated hardware and software system [7]. The instantaneous pressure waveforms of at least 10 cardiac cycles were digitized every 2 ms and stored on the hard disk of a PC for off-line post processing. During both arterial diameter and pressure measurements the spikes corresponding to the QRS complex of the electrocardiogram were acquired and stored together with the diameter and pressure signals.

B. Data Analysis

Pressure and diameter waveforms were identified according to the QRS complex of the electrocardiogram. Each cardiac cycle, both for pressure and diameter, was interpolated in time in order to obtain the same number of data points allowing calculation of the averaged cardiac cycle corresponding to the pressure signal and the averaged cardiac cycle corresponding to the diameter signal [7].

For each tonometry signal an average waveform was constructed of at least five beats. Carotid and femoral waveforms were calibrated using the procedure proposed by Kelly and Fitchet that assumes that mean arterial pressure (MAP) is nearly constant throughout the large artery tree and that diastolic pressure does not change substantially [8]. MAP was estimated at the upper arm using SBP_{bra} and DBP_{bra} values, as 38% of pulse pressure above diastolic pressure [7,9,10]. The carotid and femoral waveforms were calibrated by assigning the corresponding DBP_{bra} to the minimum value and the resulting MAP to the average value. The peak of the calibrated carotid (SBP_{Car}_Ton) and femoral (SBP_{Fem}_Ton) artery waveforms were considered as the reference systolic value.

Diameter waveforms were calibrated using linear and exponential approach. Briefly, the linear calibration method assumes that pressure and diameter are linearly related [1]. DBP_{bra} is assigned to the minimum of the distension waveform, and MAP is assigned to the area integral divided by the duration of the distension waveform. The peak of the calibrated carotid (SBP_{Car}_Lin) and femoral (SBP_{Fem}_Lin) waveforms were considered as systolic values. For the exponential calibration method, the procedure proposed by Meinders and Hoeks was used [2]. In summary, it is assumed that pressure and arterial cross-section are related by an empirically derived exponential function. The derived pressure waveform is calibrated to DBP_{bra} and MAP by iteratively changing a wall rigidity coefficient [2]. The peak of the calibrated carotid (SBP_{Car}_Exp) and femoral (SBP_{Fem}_Exp) waveforms were considered as systolic values.

Values are presented as mean ± standard deviation. Differences were compared with paired t-test and the relationship between variables was evaluated by linear regression analysis. A value of $p<0.05$ was considered statistically significant.

III. Results

Subject's characteristics are shown in table 1. A total number of 270 carotid and 64 femoral waveforms were considered for the analysis. Figure 1 shows mean carotid and mean femoral systolic pressure values estimated from linear and exponential calibration of B-mode distension waves, compared to mean carotid and mean femoral systolic pressure values obtained with tonometry.

TABLE I. SUBJECTS CHARACTERISTICS. SBP_{bra}: BRACHIAL SYSTOLIC PRESSURE, DBP_{bra}: BRACHIAL DIASTOLIC PRESSURE, PP_{bra}: BRACHIAL PULSE PRESSURE, AH: ANTIHYPERTENSIVE

	Mean±SD	Min	Max
Age (years)	51±11	24	73
Body Mass Index (Kg.m^{-2})	27±6	21	40
Sex (male, %)	60		
SBP_{bra} (mmHg)	136±16	98	193
DBP_{bra} (mmHg)	80±12	47	114
PP_{bra} (mmHg)	55±11	31	93
Hypertensive (%)	86		
AH Treatment (%)	44		

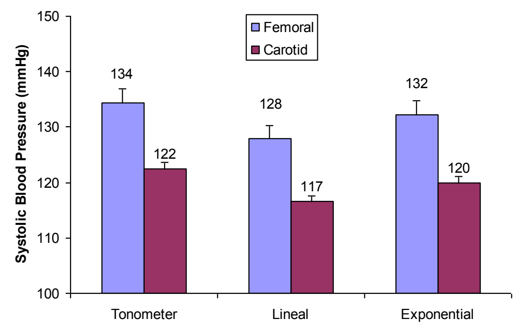

Figure 1. Mean systolic blood pressure in the carotid (n=270) and femoral (n=64) artery estimated from linearly and exponentially calibrated B-mode diameter compared to pressure measured by carotid and femoral artery tonometry

Figure 2 (left panel) shows carotid SBP estimated by the linear and exponential B-mode calibration method plotted against carotid SBP estimated by tonometry. The two methods correlated significantly (R=0.99, p<0.05).

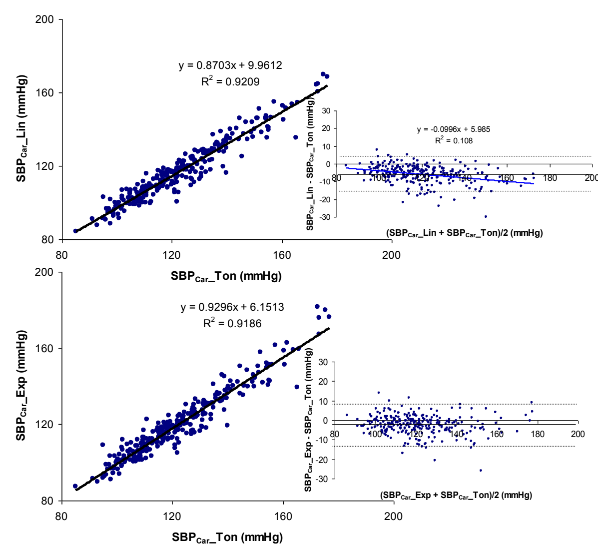

Figure 2. Left: carotid SBP by the linear (top) and exponential (bottom) diameter calibration method plotted against carotid SBP by the tonometer method (n=270). Right: Bland and Altman plots between carotid SBP values obtained using linear (top) and exponential (bottom) diameter calibration, and tonometer. The dotted line is the mean difference and the dashed lines represent the mean ± two times SD

In figure 2 (right panel), the difference between tonometry and echocardiography-derived pressure estimates is plotted against the average of the two methods. For the linear calibration approach, the mean difference between the two methods was -5.9±5.0 mmHg, whereas the range of the limits of agreement (mean ± 2 standard deviation) was -16 to 4 mmHg, showing trend with increasing pressure levels ($R=0.33$, $p<0.05$). By other side, for the exponential calibration approach the mean difference between the two methods was -2.5±5.0 mmHg, whereas the range of the limits of agreement was -13 to 8 mmHg, showing no trend.

Similarly, figure 3 (left panel) shows femoral SBP estimated by the linear and exponential B-mode calibration method plotted against femoral SBP estimated by tonometry. The mean difference between tonometry and echocardiography-derived pressure estimates was –6.4±5.6 mmHg (CI: -18;5, showing trend: $R=0.42$, $p<0.05$) for the linear calibration method and -2.1±5.7 mmHg (CI: -13;9, showing no trend) for the exponential method.

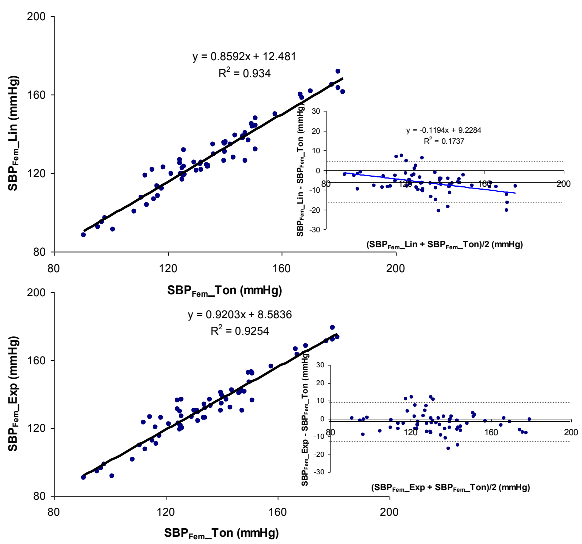

Figure 3. Left: femoral SBP by the linear (top) and exponential (bottom) diameter calibration method plotted against femoral SBP by the tonometer method (n=64). Right: Bland and Altman plots between femoral SBP values obtained using linear (top) and exponential (bottom) diameter calibration, and tonometer. The dotted line is the mean difference and the dashed lines represent the mean ± two times SD

IV. Discussion

In this study, we investigated the validity of using echographic B-mode distension waves, appropriately calibrated, to estimate systolic local arterial blood pressure in carotid and femoral arteries. Applanation tometry previously validated in animals and in human subjects [8], was used as reference method. Carotid and femoral tonometer waveforms were calibrated using the procedure proposed by Kelly and Fitchet, using DBP_{bra}, and MAP computed as 38% of pulse pressure above diastolic pressure. In a recent study, we showed that error in estimating mean arterial blood pressure from systolic and diastolic brachial values using the traditional value of 33% resulted in an underestimation of mean brachial pressure of 3%, which tended to an underestimation of carotid and femoral systolic pressure of 5%. Moreover, absolute error increases with increasing pulse pressure levels. Using a value of 38% introduced an error of only 0.1% in mean brachial pressure and of 0.2% in carotid and femoral systolic pressure estimation, independent of pulse pressure levels [7].

Non-invasive ultrasound methods for the measurement of arterial diameter waveform include B-mode [5,6], and echo-tracking [1,3,4,11,12]. Whereas echo-tracking shows high resolution within single continuous measurements, B-mode imaging has lower temporal resolution, but provides additional spatial information along the length of the artery. In addition, studies involving relative comparison of methods demonstrated that although echo-tracking systems offer higher resolution for continuous measurements, the reproducibility of discontinuous measurements of carotid artery diameter waveforms is not better with echo-tracking than with automated detection B-mode imaging systems [12]. In the present work, arterial diameter waveforms were obtained using an automatic computerized device based on B-mode imaging. The device has been previously validated against sonomicrometry in sheep, as well as against echo-tracking in humans [6].

A recent study involving 2026 subjects showed that systolic blood pressure derived from linearly calibrated echo-tracking diameter curves underestimates pressures obtained by carotid tonometry by 6.4±4.1 mmHg, and that absolute error increased with increasing pressure levels. By other side, exponentially calibrated echo-tracking diameter curves underestimates pressures obtained by carotid tonometry by only 1.9±3.9 mmHg, independent of the level of pressure [4]. Our results are very similar: linear and exponential procedures underestimate carotid tonometry by 4.7% and 1.9% respectively, showing a trend only for the linear calibration procedure. Similarly, linear and exponential procedures underestimate femoral tonometry by 4.6% and 2.1% respectively, showing a trend only for the linear calibration procedure.

V. Conclusion

The alternative method based on B-mode ultrasound image analysis and implementation of an iterative calibration model was found to allow an accurate and precise estimation of systolic local arterial pressure, with an underestimation error of ~ 2% independent of pressure levels, when compared to carotid and femoral arterial tonometry

Acknowledgment

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