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Carotid distension waves acquired with a fiber sensor as an alternative to tonometry for central arterial systolic pressure assessment in young subjects

C. Leitão [a,*], P. Antunes [a], J.L. Pinto [a], J.M. Bastos [b], P. André [c]

[a] Instituto de Telecomunicações, I3N and Department of Physics, University of Aveiro, 3810-193 Aveiro, Portugal
[b] Centro Hospitalar do Baixo Vouga E.P.E., Avenida Artur Ravara, 3810-501 Aveiro, Portugal
[c] Instituto de Telecomunicações and Department of Electrical and Computer Engineering, Instituto Superior Técnico, University of Lisbon, 1049-001 Lisboa, Portugal

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A B S T R A C T

In this work it is evaluated the possibility of central blood pressure assessment using distension waves, obtained with a low cost optical fiber sensor, instead of regular arterial tonometry. Carotid distension and pressure waveforms were acquired in 15 young subjects. Form factors, root-mean-square error (RMSE), harmonic decomposition and central systolic pressures for both techniques were analysed. The pressure waves assessed by the piezoelectric probe had lower form factors than the ones assessed by the optical fiber sensor, due to the different nature of the waves (51.05 ± 5.15% versus 40.53 ± 5.70%), translating in a RMSE of 14 ± 2%. Regarding the harmonic analysis, paired *t*-tests shown that the first four harmonics are not significant different ($p \leqslant 0.05$), and Pearson correlation studies retrieve that the 2nd–7th harmonics are correlated ($p \leqslant 0.03$). Central systolic pressures were also obtained with both techniques displaying a very strong Pearson correlation (0.99) and a small difference of 0.63 ± 2.40 mmHg. These pre-clinical results support a future clinical validation study in larger and broader cohorts.

1. Introduction

Arterial brachial blood pressure (BP) and pulse morphology do not invariably reflect central blood pressure values and features [1]. It is now becoming clear that arterial pressure should be evaluated not only by brachial BP measurements, but also by central BP assessment [2]. Through the proximal arterial tree, in contrary to diastolic (DP) and mean arterial pressure (MAP), pulse pressure is not constant. Systolic pressure (SP) increases towards peripheral arteries [3], inferring that in the brachial artery, which a muscular artery, pulse pressure will generally be higher than in carotid and aortic arteries, both elastic.

Pulse waveform measurements are usually performed by arterial tonometry with electromechanical probes, such as the case of Complior Analyse® (*Alam medical*) and SphygmoCor® (*AtCor medical*). These pressure probes are pressed to superficial arteries in order to flatten them and sense the pressure changes in its interior [4]. Several studies have also explored the use of distension waves to calculate central pressure parameters [5–7].

In this scope, our team has been working on cost effective techniques based on plastic optical fibers (POF) [8,9], aiming the promotion of central BP assessment as a primary health care evaluation method. Optical fiber sensors have unique features to fulfill medical instrumentation requirements, such as immunity to electromagnetic radiation and electric insulation from the patient, improving the safety of medical devices and even allowing monitoring physiological signals during magnetic resonance imaging [10].

The aims of this study were to evaluate the similarity of distension and pressure pulses of young subjects, and to estimate the carotid pressure using carotid distension waves assessed with an intensity based optical fiber device, designated as POFpen. The pulse waves were matched in the time and frequency domain with tonometric signals obtained by a standard medical device (Complior analyse). Central systolic pressures (cSP) estimated by both technologies were also compared.

2. Material and methods

Within this pre-clinical study, 15 subjects were recruited, with ages between 22 and 34 years old, after giving their informed consent. In each one, the carotid pulses were acquired with the two

* Corresponding author.
E-mail address: catia.leitao@ua.pt (C. Leitão).

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probes, POFpen and Complior, as described in the following subsections.

2.1. Optical fiber probe - POFpen

The optical fiber probe used in this study, presented on previous works [8,9], consists in a polylactide (PLA) 3D printed pen supporting a 2.2 mm outer diameter (1 mm core) step-index POF (*GM 4001, Mitsubishi Rayon Co*). The sensing system is composed by the pen, a 2×1 optical fiber coupler (*IF562-Industrial fiber optics*), a red LED source (*IFE96-Industrial fiber optics*), a photodiode (*IFD91-Industrial fiber optics*) and the controlling electronics. The system has an acquisition rate of 500 samples/s, and a Bluetooth module allowing remote data acquisitions. A *LabVIEW*® developed application permits to remotely control the hardware and to automatically save the data in the $*$.*txt* file format, which can be loaded later for pulse sequence evaluation and average pulse calculation with a *Matlab*® application.

In Fig. 1a it is represented a scheme of the probe working principle. The acquisition process begins with a small reflected adhesive placement on the left carotid surface, where the highest pulsatility is felt. As the pressure waves travels through the carotid, the artery distends as response to the instant inner pressure changes, moving the reflector on top of the artery. Since the probe works in reflection, the applied optical signal to the adhesive is reflected and received by the same fiber, wherein the intensity of the collected signal is modulated by the fiber-reflector distance changes. Consequently, the received optical signal intensity varies proportionally and with the same pattern than the carotid wall distension. It should be noticed that the optical signal from the LED does not interact with the skin, only with the reflector that is placed on its surface, as can be seen in Fig. 1b. The probe end is hollow, allowing the stabilization of the surrounding area without press the artery in the acquisition location.

2.2. Pressure probe - Complior Analyse® (ALAM Medical)

Complior Analyse is a validated commercial system that uses piezoelectric sensors to acquire pressure waves, allowing central pressure and pulse wave velocity measurement at an acquisition rate of 1000 samples/s. After the measures the system retrieves the arterial pulse shape and the respective central arterial pressure and/or pulse wave velocity.

2.3. Data acquisition and treatment methodologies

POFpen and Complior have the same clinical exam procedure. The acquisition process begins with the subject on supine position followed by a short cardiovascular risk questionnaire. The patient rests for about 10 min before the data acquisition, which usually takes no more than 2 min, depending on the subject's anatomy.

The brachial blood pressure was assessed before and after each measure with the pulse wave devices, using a commercial pressure cuff (*M6 Comfort, OMRON*). POFpen and Complior cannot be used simultaneously, as in each patient there is usually only one optimal location for pulse waveform acquisition. After carotid pulses acquisition, the resulting mean arterial waveforms were calibrated with the brachial pressures measured right after each acquisition.

2.3.1. Central pressure calculation

cSP calculation was performed using Eq. (1), considering that *DP* and *MAP* are constant through the proximal arterial tree [11].

$$cSP = DP + \frac{MAP - DP}{Mp} \tag{1}$$

DP and *MAP* are obtained in the brachial artery and M_p is the mean point of the assessed carotid wave, which corresponds to half the integral of the total normalized pulse. *MAP* was calculated with the usual equation considered by the medical community:

$$MAP = DP + \frac{1}{3}(SP - DP). \tag{2}$$

2.3.2. Waveform and central pressure comparison

Curves from both devices were superimposed in time domain, as performed in similar studies [12,13], where form factor (*FF%*) and root-mean-square error (*RMSE*) were calculated. *FF%* is and indicator of the pulse wave shape, relating *MAP* and *DP* with the assessed central pulse pressure ($cPP = cSP - DP$), and is calculated using Eq. (3). *FF%* of both techniques were compared by paired *t*-tests and Pearson correlation coefficients.

$$FF\% = \frac{MAP - DP}{cPP} \times 100 \tag{3}$$

The *RMSE* allows the quantification of the waveform values deviation across the entire pulse wave and was calculated to analyse the absolute difference between the distension and pressure waveforms.

To analyse the frequency components of the waves assessed with both techniques, Fourier decomposition was performed, after which the amplitudes of each harmonic (until the 8th) were compared. The difference between techniques was statistically analysed by paired *t*-tests and Pearson correlation.

3. Results

The characteristics of the 15 subjects that volunteered for the study, as well as the brachial arterial pressures measured through

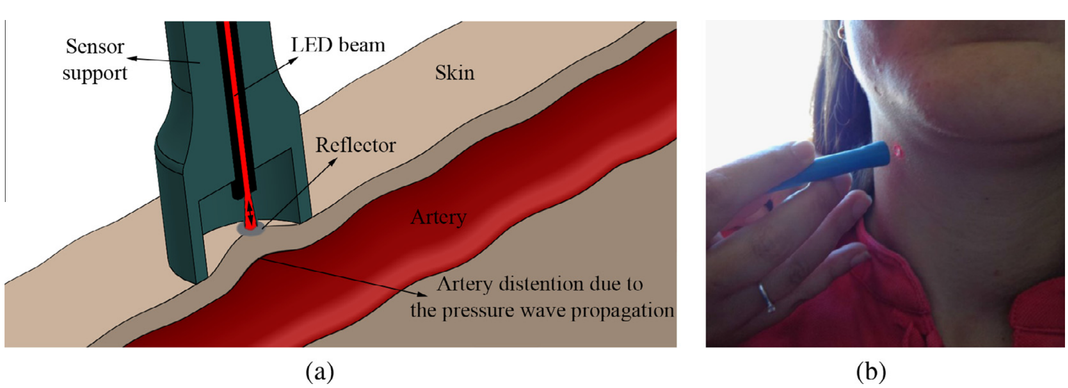

Fig. 1. *POFpen*: (a) schematization and (b) photograph of the application on the carotid artery's surface.