e-PWV: A Web Application for Assessing Online Carotid-Femoral Pulse Wave Velocity

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Abstract. This article presents e-PWV, a web application for the determination of Pulse Wave Velocity (PWV) running on a web platform called NooLib. e-PWV has been applied on signals recorded by an ultrasound system (PWV_{et}, Aloka, Japan) and representing the arterial diameter changes in carotid and femoral sites. PWV_{et} measurements were compared to PWV recorded by a tonometric technique (PWV_{pp}, PulsePen, Italy). The study was conducted on 120 patients. We found an excellent correlation of r = 0.95 between PWV_{et} et PWV_{pp} ($P < 0.0001$; 95% confidence interval of 0.91–0.96; $PWV_{et} = 0.88 \times PWV_{pp} + 0.57$). We observed a small offset of $-0.33\,\mathrm{ms}^{-1}$ on the Bland-Altman plot with a limit of agreement from -2.21 to $1.54\,\mathrm{ms}^{-1}$. Our results suggest that e-PWV application can produce online a reliable marker of the regional aortic stiffness using an echotracking system.

Keywords: Arterial stiffness · Echo-tracking · Ultrasound · Web

1 Introduction

Nowadays, arterial stiffness plays a major role in the development of cardiovascular diseases [1]. Carotid-femoral Pulse Wave Velocity (PWV) represents the most established index of regional aortic stiffness and numerous techniques

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allow its determination non-invasively [2]. These techniques rely generally on the recording of one or several arterial hemodynamic parameters (pressure, velocity or diameter) and embed a software for the automatic computing of pulse wave velocity based on a foot-to-foot method [3].

We present, here, a web application, called e-PWV, allowing the online assessment of the pulse wave velocity between two arterial sites. The application runs on a homemade web platform, called NooLib. NooLib can host algorithms coming from scientific research and transform them in an easy to use application. NooLib ensures the data security and intellectual property of algorithms since all applications run on the server side in a Linux container.

In practice, e-PWV needs one signal per arterial site representing an arterial hemodynamic parameter as a function of time and synchronized with the electrocardiogram (ECG) signal. Thereafter, the application applies an intersecting tangent algorithm in order to detect, for each site, the foot of the waveform. The transit time Δt between the two sites is computed as the time delay between the feet of the waveforms and the velocity is deduced as the ratio between the distance d and Δt where d represents the distance between the two anatomical sites.

In this article, e-PWV has been developed because no algorithm is currently embedded in ultrasound systems for the determination of carotid-femoral PWV. Actually, ultrasound systems (B-mode) that can implement echo-tracking technology (ET) allow visualization of the blood vessels. The recording of local diameter changes in peripheral arteries (namely carotid or femoral arteries) is feasible. Then, the carotid and femoral diameter waveforms can be saved separately in a text file and the transit time between the two sites can be computed from a foot-to-foot method.

A bicentric study was conducted with the hospital of Angers (France) and the university of Pisa (Italy) in order to validate this approach. The study was developed to assess the accuracy and repeatability of carotid-femoral PWV measurements using the e-PWV application as compared to the reference tonometric technique [4].

2 Materials and Methods

2.1 The NooLib Platform

The NooLib platform (www.noolib.com) has two goals:

1. For non-developers: offer them the opportunity to use algorithms without skills in programming languages.
2. For developers: have a better interaction with the users and the applications on the platform.

NooLib therefore represents a collaborative platform where research can be shared and compared through the use of applications online.

Technically, NooLib is a web platform, currently in beta, which enables researchers to deposit algorithms written in Java/Python/Javascript/PHP or

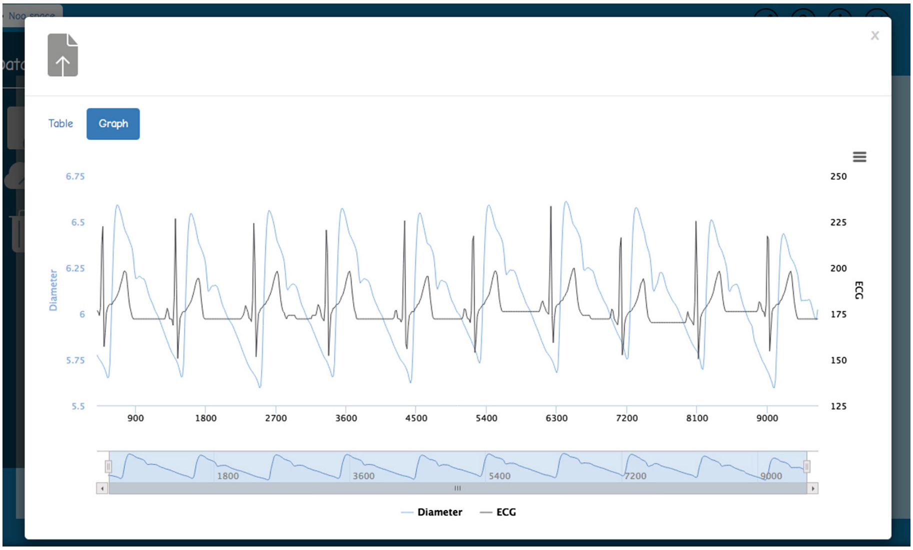

Fig. 1. The data manager on the NooLib platform. We can see two signals coming from echotracking technology representing the arterial diameter changes and the ECG signal. The x-axis represents time in second and the y-axis is graduated according to data loaded (in mm for the arterial diameter changes and arbitrary unit for the ECG signal). Before injecting data into an application, we can select an appropriate interval and save it.

Matlab and transform them into an application with an user-friendly interface. The kernel of the platform relies on an operating-system-level virtualization method for running multiple isolated Linux systems on a control host using a single Linux kernel. The Linux kernel provides a control group functionality that allows limitation and prioritization of resources (CPU, memory, block I/O, network, etc.). Then, NooLib enables each algorithm to be run on the server side in an isolated environment maintaining a high degree of security and ensures intellectual property rights for users.

A data manger is present on the platform in order to offer the opportunity for users to upload their data before being used in an application online. This allows applications to avoid a pre-control of data before running and for users to select and apply pre-processing on data before injecting them into an application (see Fig. 1). Currently, the data manager allows uploading files in csv, txt or edf format and images in jpg, jpg2000, png or Dicom format.

2.2 Population Studied

A total of 120 patients (69 men) between 18 and 81 years of age (mean age: 43 ± 18 years) were enrolled to the study. The population was initially referred for vascular screening for atherosclerosis, metabolic disease or inherited diseases including patients with hypertension, Type 2 diabetes and normal subjects. All patients received detailed information about the purpose of the study and gave their consent. Ethics committees in both sites approved the study.

2.3 Carotid-Femoral Pulse Wave Velocity Recorded by the Tonometric Technique

A high-resolution tonometer (Pulsepen, DiaTecne, Milan, Italy) was used to record the transcutaneous carotid-femoral PWV (PWVpp) in the right common carotid and femoral arteries consecutively [5]. The distance between the two recording sites was measured with a ruler and calculated as the direct carotid-femoral distance corrected by a factor equals to 0.8 as recommended by the European Society of Hypertension [3]. Carotid-femoral PWV is determined using the intersecting tangent algorithm and expressed in ms^{-1}.

2.4 Recording of Carotid and Femoral Diameter Waveforms by Echotracking System

The ECG signal, the carotid diameter waveform and the femoral diameter waveform were obtained by a high-resolution ET ultrasound system (US) coupled to a standard B-mode imaging (Alpha 10, Aloka, Japan). To track the displacement of arterial walls during cardiac cycle, wall-tracking calipers were set to the intima-media interface of the near and far arterial wall, and wall movements were followed automatically by the system with high spatial and temporal resolution. The carotid and femoral diameter changes were exported in text format for an importation in NooLib.

2.5 Carotid-Femoral Pulse Wave Velocity Using e-PWV Application

e-PWV has been written in Python 3. The application allows a sample rate parameter which can be adjusted in NooLib before running the application. It represents the sample rate of signals inputted into the application. A low-pass filter with a cutoff frequency at 40 Hz is applied on each signals received in order to improve the signal to noise ratio. A first algorithm detects each R-peaks of ECG signal and each cardiac cycle is isolated for the carotid and the femoral arteries. Then, the carotid and femoral distension waveforms were averaged over ten cardiac cycles. In the case where less than ten cardiac cycles are detected, e-PWV performs an average over the total of cardiac cycles detected. A second algorithm, based on an intersecting tangent method, was applied to the mean curves in order to detect the feet of the carotid and femoral waveforms. The calculation of PWV_{et} was established as the ratio between the distance of the two sites (carotid and femoral arterial sites) and the time delay evaluated between the feet of the waveforms. The distance between the two sites was the same as used for the PWV_{pp} value using the tonometric technique in order to prevent bias between both techniques.

2.6 Comparison of PWV_{pp} and PWV_{et}

Two consecutive ET and tonometric measurements were carried out by experienced operators (C. Palombo and G. Leftheriotis). The mean of the 2 measurements was retained for our analysis. ET and tonometric examinations were made in random order. The systolic and diastolic brachial arterial blood pressures were collected by an automatic sphygmomanometer (Welch-Allyn, NY, USA) with an appropriate cuff size.

2.7 Statistical Analysis

All statistical analyses were performed with the Prism software (GraphPad, La Jolla, CA, version 5.0). Agreement between PWV_{pp} and PWV_{et} variables was assessed using a Student's paired t-tests and Bland-Altman plots. The relationship among PWV_{pp} and PWV_{et} was evaluated by linear regression. Repeatability of PWV_{pp} and PWV_{et} measurements were estimated by calculating a within-subject coefficient of variation for repeated measurements and Bland-Altman plots. For all statistics, a P value of <0.05 was considered statistically significant.

3 Results

The biometric and hemodynamic characteristics of the patients are presented in Table 1. PWVpp and PWVet measurements showed respectively a good signal-to-noise ratio of 91% and 94% of the recordings. It was only when wave foot detection was feasible that PWV_{pp} and PWV_{et} were taken into account in the statistical analysis.

No significant difference was observed between the mean PWV_{pp} ($7.40 \pm 2.85\,\text{ms}^{-1}$) and the mean PWV_{et} ($7.06 \pm 2.61\,\text{ms}^{-1}$). We found a significant Pearson correlation coefficient of $r = 0.94$ between the 2 variables ($P < 0.0001$; 95% confidence interval 0.91–0.96; $PWV_{et} = 0.88 \times PWV_{pp} + 0.57$). The Bland-Altman plot showed a small offset of $-0.33\,\text{ms}^{-1}$ with a limit of agreement from -2.21 to $1.54\,\text{ms}^{-1}$ between the 2 variables.

Table 1. Main clinical characteristics of patients. Results are displayed as Mean±SD and Mann-Whitney t-test: $^{*}P < 0.05$ vs overall population $^{**}P < 0.01$ vs overall population $^{***}P < 0.001$ vs overall population

Parameter	Overall (n = 120)	Pisa (n = 80)	Angers (n = 40)
Age	43 ± 18	38 ± 18*	52 ± 15**
Systolic blood pressure (mmHg)	119 ± 14	118 ± 14	121 ± 13
Diastolic blood pressure (mmHg)	72 ± 10	71 ± 10	75 ± 10
PWV_{pp} (m/s)	7.40 ± 2.85	6.05 ± 1.70**	10.04 ± 2.80***
PWV_{et} (m/s)	7.06 ± 2.61	5.76 ± 1.50***	9.52 ± 2.51***

For all participants, we observed a small coefficient of variation of 5.8% and 8.5% between two consecutive carotid-femoral PWV_{et} and PWV_{pp} respectively, without significant differences in the within-subject repeatability. Finally, comparing two successive PWV_{pp} measurements, the Bland-Altman plot showed a small offset of $-0.08\,\mathrm{ms}^{-1}$ with a limit of agreement from -2.11 to $1.95\,\mathrm{ms}^{-1}$. The same analysis showed a systematic offset of $0.14\,\mathrm{ms}^{-1}$ with a limit of agreement from -1.71 to $2.00\,\mathrm{ms}^{-1}$ for two successive PWV_{et} measurements.

4 Conclusion

The accuracy of the ET technique in the assessment of the carotid-femoral PWV using e-PWV application was demonstrated in this study showing an excellent correlation with the tonometric technique. The Bland and Altman analysis also revealed a small offset between both techniques and the repeatability between the two techniques showed no significant difference. The results may indicate that tonometric techniques and ultrasound system could be interchangeable. This leads to the conclusion that e-PWV application on NooLib can compute online a reliable marker of the carotid-femoral PWV using an echo-tracking system. Thereafter, e-PWV could be validated for other technologies recording an hemodynamic parameter of the artery coupled to an ECG signal. For example, tonometric signals could also be extracted for an analysis online of the aortic stiffness using the e-PWV application.

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