Aortic-Finger Pulse Transit Time vs. R-derived Pulse Arrival Time: a Beat-to-Beat Assessment

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Abstract

Due to the difficult identification of the Aortic valve Opening (AO), Pulse Transit Time (PTT) is often surrogated by the Pulse Arrival Time (PAT) in which AO is approximated by the R peak in the ECG signal. This procedure introduces a fraction of the Pre Ejection Period variability into the PAT dynamics and makes the PAT variability partially different from the PTT variability.

In this pilot study we aim to quantify the possible discrepancies between PTT and PAT dynamics on a beat-to-beat basis.

In 5 sitting healthy subject we simultaneously recorded ECG, continuous finger blood pressure and the chest micro-accelerations produced by the heart contraction (the seismocardiogram) before and after a 100W exercise at the cycloergometer.

When compared to PTT, PAT is characterized not only by the expected greater mean value but also by a larger beat-to-beat variability. The spectral analysis and a subsequent averaging of the data indicates that the correlation between PTT and PAT dramatically increases when the high frequency components of their variability are removed.

1. Introduction

Pulse Transit Time (PTT) is the time needed by the blood pressure pulse to propagate from the aorta to a distal artery.

Since PTT depends on blood pressure, most of the attention on this parameter is currently focused on the possibility to obtain a non-invasive cuff-less blood pressure estimation from its analysis. However, PTT also depends on viscoelastic artery wall properties [1], thus the extraction of blood pressure information from its variability is a complex and still open issue.

For the PTT measure it is necessary to detect the instant of the Aortic Valve opening (AO) and the arrival of the Blood Pressure (BP) wave at a distal artery site, commonly the fingertip (see fig. 1).

While the distal measure may be easily detected (i.e. by tonometry or photoplethysmography), the AO event is relatively more difficult to be identified by current techniques, and it is usually approximated by the R peak in the ECG signal. The R derived pulse transit time is usually termed Pulse Arrival Time (PAT). PAT and PTT are often considered interchangeable and bear similar information, but this assumption is risky because, as shown in fig 1, PAT includes not only the PTT but also a large fraction of the Pre Ejection Period (PEP).

In this pilot study we focused on the above issue by investigating the relationship between PAT and PTT on a beat to beat basis. For the PTT estimate, AO was identified by using the seismocardiogram as detailed in the next section.

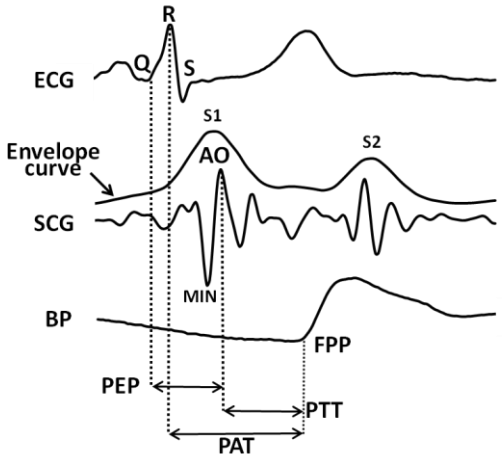

Figure 1. Typical ECG , SCG and finger blood pressure waveforms occurring at every heart beat, and the fiducial points used for the measure of PEP, PAT and PTT (see text for description and acronyms).

1.1. The seismocardiogram

At each heart beat the tiny vibrations produced by the heart contraction propagate up to the chest wall. These vibrations are associated with specific mechanical events of the cardiac cycle, including the opening and closure of heart valves and may be measured by placing an accelerometer on the sternum of the subject. The dorso-

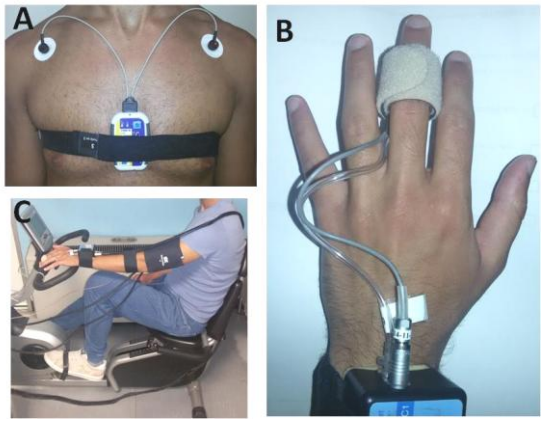

Figure 2. Instrumentation used for the study. *Panel A*: the MagIC-SGC placed on the subject's thorax. *Panel B:* detail of the finger cuff used to detect BP. *Panel C:* detail of the subject on the cycloergometer

ventral component of the resulting acceleration is known as seismocardiogram (SCG) [2]. The typical SCG waveform occurring at each heart beat is illustrated in Figure 1 together with the ECG and the BP pulse measured at the fingertip. As indicated in the figure, one of the peaks in the SCG waveform is specifically associated with the AO. The correspondence between this SCG fiducial point and the real opening of the valve was previously verified by comparisons with ultrasound measures [3,4].

2. Methods

2.1 The experimental protocol

Five healthy volunteers (1 f, 4 m, aged 23-32 years) were recruited for this study.

SCG and ECG were detected by using a custom electronic unit previously developed in our lab (details may be found in [5]). This unit includes a triaxial accelerometer (Freescale, MMA8451Q) and is usually connected to a sensorized vest embedding textile ECG electrodes but in this study it was connected to traditional adhesive ECG electrodes (fig.2A). During the experiments this unit was fastened to the sternum of the subject by an elastic band for the SCG assessment. Continuous finger arterial BP was simultaneously recorded by the Finometer model1 (FMS, Amsterdam NL) with the finger cuff mounted around the middle finger of the left hand (fig. 2B). In this study, the finger BP profile was used to measure PAT and PTT (see details hereafter), while for the comparison of transit times with BP values we considered the reconstructed brachial BP, also provided by the Finometer.

A synch signal was generated by the electronic unit and transmitted to the Finometer for the alignment of the recordings.

A 15-min continuous data acquisition was made while the subject was sitting on a cycloergometer. In the first 5 minutes the subject stayed still (REF), then pedaled for 5 minutes at 100W and finally recovered for additional 5 minutes (R100). In this study we considered data at REF and R100.

2.2 Data analysis

Using a specific algorithm developed in Matlab, ECG, SCG and finger BP were aligned. Subsequently (see fig. 1), for each heart beat (a) we identified the time position of the Q, R and S waves in the ECG; (b) estimated the envelope curve of the SCG; (c) identified the SCG zone under the S1 peak of the envelope curve; (d) within the selected zone, we localized the first SCG minimum (MIN) occurring after the end of the S wave in the ECG; (e) identified the AO fiducial point as the next SCG peak following MIN; and (f) in the finger BP signal, detected the foot of the pressure pulse (FPP).

The time position of the R and AO peaks was determined after parabolic interpolation to increase the temporal resolution.

Finally, with reference to fig. 1, the following indexes were derived on a beat-to-beat basis: PEP= time delay from Q to AO, PTT= time delay from AO to FPP, PAT = time delay from R to FPP, and RRI = time delay between consecutive R peaks.

The relation between PAT and PTT was investigated by considering first the overall beat-to-beat variability of the transit times, and then their short-term and long-term variability components separately.

3. Results

Mean values, standard deviation and coefficient of variation of RRI, PAT, PTT and SBP are reported in table 1 as average over the group of 5 subjects. When compared to PTT, at REF and R100 PAT is characterized not only by the expected greater mean value because of the PEP contribution, but also by a larger variability.

Both PAT and PTT mean values importantly decreased

Table 1. RRI, PAT and PTT global variability (n=5).

	REF			R100		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
RRI	865.3	61.3	7%	809.4	64.4	8%
PAT	206.7	7.7	3.8%	182.5	8.8	4.8%
PTT	120.4	6.6	5.5%	95.0	7.6	8%
SBP	109.2	7.3	6.7%	125.8	7.6	6.1%

SD=standard deviation; CV=coefficient of variation.
Mean and SD are expressed in ms

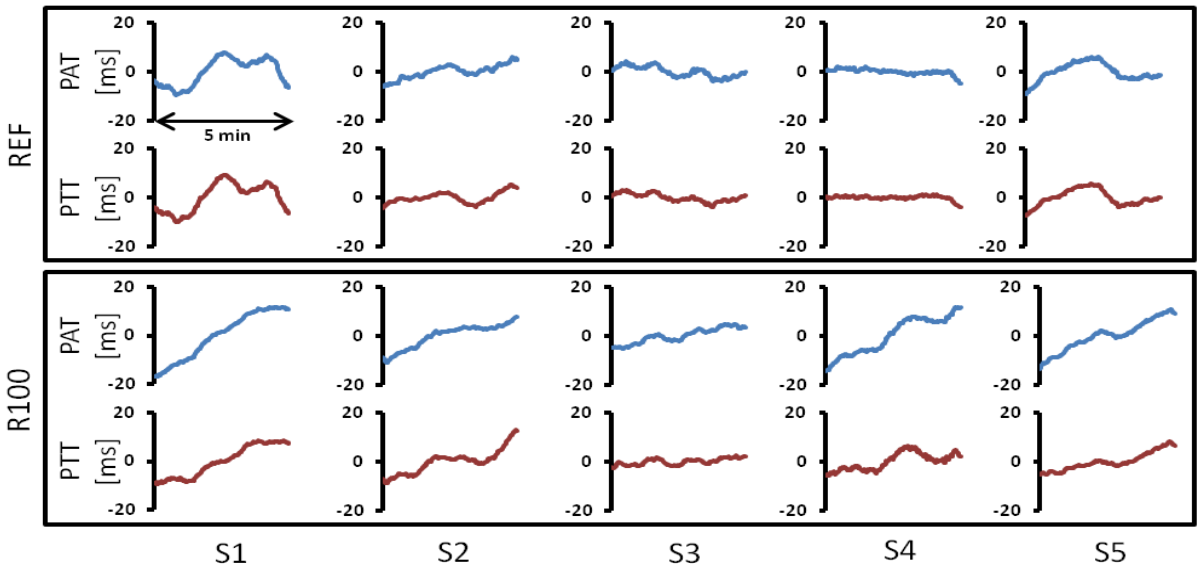

Fig. 4. Individual PAT and PTT profiles after the removal of the short term components obtained by the filtering procedure. Data refer to REF (*upper panel*) and R100 (*lower panel*) conditions. To facilitate the data comparison, the mean value was removed from each profile.

after exercise, coherently with the SBP increase observed in R100, while their standard deviation tended to increase.

The PAT vs. PTT linear correlation was also estimated by considering all beat-to-beat values. The resulting coefficient of determination, R^2, was 0.67 at REF and 0.65 at R100.

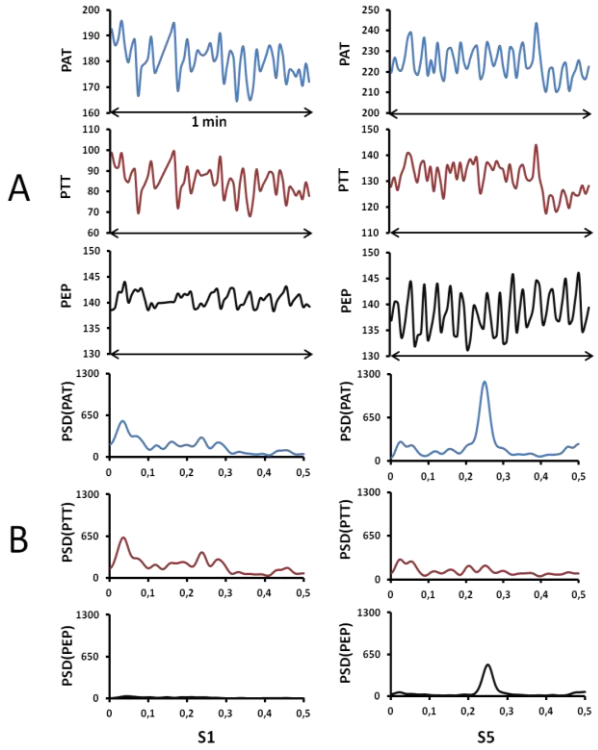

Fig. 3 *A)* Detail of 1 minute PAT , PTT and PEP time profile for subject 1 (left side) and subject 5 (right side) at REF. *B)* Corresponding PAT, PTT and PEP spectra estimated over the whole REF period. Time profiles are expressed in ms, power spectral densities are expressed in ms^2/Hz

3.1. PAT vs. PTT short term variability

Our investigation of the short term components of PAT and PTT variability was based on the spectra analysis. The spectral estimation was obtained by the Welch method with a 60-s windowing and the spectral power density was integrated in the low frequency (LF, 0.04-0.14 Hz) and high frequency (HF, 0.15-0.4 Hz) bands as defined in [6].

The analysis over the group evidenced some differences between PAT and PTT spectral characteristics. Indeed, as compared with REF, the LF power decreased after exercise more in PAT (moving from 15.32 ms^2 to 5.74 ms^2), than in PTT (from 11.14 ms^2 to 7.72 ms^2). Conversely the HF power decreased for PAT (from 27.04 ms^2 to 12.46 ms^2) and tended to increase for PTT (from 17.54 ms^2 to 24.48 ms^2) after exercise.

During the analysis of the data at REF, we also noticed two interesting cases, reported in fig. 3. In the first subject (left side of the figure), the spectra of PAT and PTT are pretty similar, while in the other subject (right side) the spectra are clearly different with a marked influence of respiration in the PAT spectrum. Following this observation, we also estimated the beat-to-beat profile of PEP and the corresponding spectra (both shown in fig. 3). It is apparent that in the case of the subject with similar PAT and PTT spectra, the power of PEP is minimal. On the contrary, in the other subject, the difference in the PAT and PTT spectra is associated with a remarkable power in the PEP spectrum at the respiratory frequency. This finding provides evidence of the possible PEP

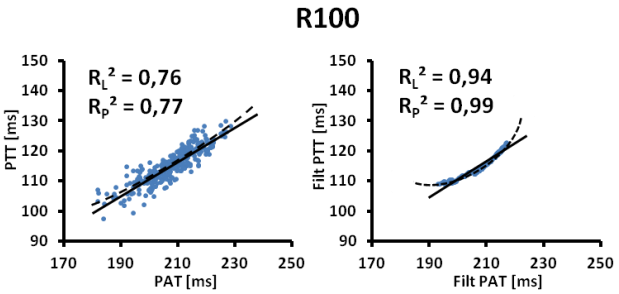

Fig. 5 PTT vs. PAT scatter plots before *(left panel)* and after *(right panel)* filtering. Data refers to subject 5 at R100. R_L^2 and R_P^2 are the coefficients of determination computed by linear and parabolic regression analysis, respectively.

influence on PAT variability.

3.2. PAT vs. PTT long term variability

In order to investigate the relationship between the long term components of PAT and PTT variabilities, the beat-to-beat time series were low pass filtered by a moving average filter with a window size of 31 samples.

Figure 4 illustrates the filtered PAT and PTT profiles for all subjects at REF and R100. It is evident the similarity in the trends of the two variables. This similarity was confirmed by the linear correlation analysis. Indeed, after filtering, R^2 increased from 0.67 (observed by considering unfiltered data) to 0.75 at REF and from 0.65 (unfiltered) to 0.85 at R100.

The important increase in the linear coupling between PAT and PTT after the removal of the fastest components of variability is even more clear from the scatter plots shown in fig. 5. They refers to one subject of our group at R100. It is apparent that after filtering, there is a massive reduction in the dispersion of the cloud of points. The same trend was invariably observed in all subjects of the group.

In the subject shown in fig.5, we also observed that, after filtering, the correlation between PAT and PTT profiles could not be completely explained by the linear regression curve. Therefore, we also considered a parabolic regression curve and the resulting coefficient of determination, R_P^2, further increased to 0.99.

4. Conclusions

In this paper we used a novel methodology to estimate PTT based on the localization of the Aortic valve Opening by the seismocardiogram signal. This allowed us to have a characterization of differences between the real pulse transit time (PTT) and R-derived transit time (PAT) on a beat-to-beat basis.

The analysis considered a group of 5 subject before and after mild exercise. Although further investigations are required to confirm our findings, the preliminary results suggest that:

1. PAT and PTT dynamics may importantly differ, and this difference is subject-dependent.

2. The PAT vs. PTT linear coupling is importantly strengthened by the removal of the fastest components of their variabilities.

3. Most of the possible influence of PEP on PAT, if any, occurs on the short term components of PAT variability.

Apart from the small sample size, another possible limitation of the study refers to the window size of the filtering procedure. In this pilot analysis we arbitrarily selected a size of 31 samples, however we cannot exclude that a better tuning of the filter cutoff frequency might lead to an even closer correlation between PAT an PTT.

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