PULSE PRESSURE VARIATION CAN AFFECT READINGS OF BEAT-TO-BEAT ARTERIAL COMPLIANCE MEASUREMENT

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Abstract. Beat-to-beat finger arterial compliance *C* is calculated applying two different estimates. The 1st estimate, $C_1=\Delta V/\Delta P$ (where ΔP is the finger arterial pulse pressure and ΔV is the corresponding pulsatile volumetric change), is commonly used by investigators. The 2nd estimate, $C_2=dV/dP$ is based on the calculation of the slope of the pressure-volume (*P-V*) relationship from the first derivatives *dV/dt* and *dP/dt* of the recorded volume and pressure pulses near the point of maximum slope. Time courses of the finger arterial blood pressure and volumetric changes are recorded by applying the Finapres monitor (Ohmeda, USA) and the UT9201 monitor (University of Tartu, Estonia), respectively. The results of the study demonstrate that even in case of fixed transmural pressure, the pulse pressure variation can affect readings of the beat-to-beat arterial compliance measurement when the 1st type of estimation is applied. The 2nd estimate is less sensitive to the changing pulse pressure and can be preferred when considerable alterations in the amplitude of the arterial pulse pressure exist.

Keywords: finger pulse pressure, beat-to-beat arterial compliance, vascular tone, viscoelastic properties, Finapres

Introduction

The viscoelastic properties of the vascular bed provide useful and important information for the evaluation of physiological and pathophysiological changes in human hemodynamics. To obtain this information, the pressure against volume (*P-V*) relationship should be measured.

The main character of the non-linear (S-shape) arterial pressure-volume relationship is shown in Fig. 1. The slope of the *P-V* curve is known as the vascular compliance $C= dV/dP$.

Because of the viscoelastic properties of the arterial wall, the original recordings of the arterial compliance are different for static and dynamic measurement [1-5]. It is obvious that the most comprehensive information can be obtained by applying the continuous (beat-to-beat) measurement [2-3, 5-6].

In beat-to-beat implication, very often, the compliance is measured by simultaneously observing the pulsatile blood volume change and the corresponding change in the blood pressure. In this case, the formula $C= \Delta V/\Delta P$ is applyed, where ΔP is the arterial pulse pressure and ΔV the corresponding change in arterial volume.

It should be pointed out that owing to non-linearity of the arterial *P-V* relationship, the obtained values of compliance are related to the local mean blood pressure. This can easily be detected observing Figure 1: vascular compliance decreases when transmural pressure ($P_{transm}= P_{arterial} – P_{cuff}$) increases, and vice versa.

This shortcoming can be overcome by performing measurements at a fixed transmural pressure. In this case changes in the local mean blood pressure level do not affect the results of compliance measurement. Tanaka et al. [7] have carried out beat-to-beat compliance measurements at a constant transmural pressure equal to 40 mm Hg. The value 90 mm Hg is also often used [8] as it is close to physiological situation. When recording the dynamic compliance in the physiological range of pressures (without applying an external cuff pressure), the pressure range between the systolic (P_{syst}) and diastolic (P_{diast}) pressure is covered.

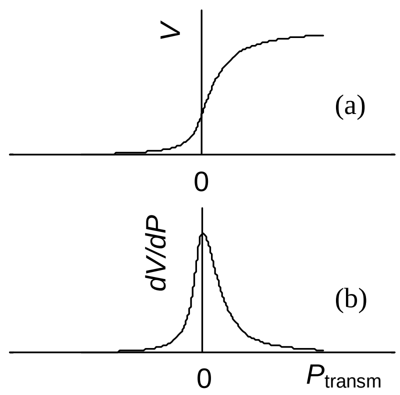

Figure 1: Arterial pressure-volume relationship (*a*) and compliance (*b*).

Some authors [9] prefer an unloaded situation of the arterial wall ($P_{transm}= 0$) since measurements on isolated arteries [1] have demonstrated that this region should be of the most interest in situations when viscoelasticity of the arterial wall is changed. Bank et al. [10] have demonstrated that a drug effect on brachial arterial compliance is more apparent at low transmural pressure and they suppose that the ability to differentiate normal vessels from the diseased ones might be improved at a lower transmural pressure.

In our previous study [11] we estimated beat-to-beat changes in the finger arterial compliance at $P_{transm}= 0$ during light physical exercise (two successive handgrips). Finger arterial pulse pressure was measured by the Finapres monitor while volume pulses at an automatically controlled condition $P_{transm}= 0$ were recorded by the UT9201 monitor.

Even when experiments are conducted at a fixed transmural pressure, however, a variation in the beat-to-beat compliance may take place due to changes in the pulse pressure amplitude. This was the reason why we could not decide strictly in our previous investigation whether the detected changes in the beat-to-beat compliance were caused only by an alteration in the arterial wall *P-V* relationship or by a rise in the pulse pressure amplitude.

An influence of the pulse pressure variation on the readings of beat-to-beat arterial compliance measurement has received little attention in the literature.

In the present study we computed the beat-to-beat compliance as a ratio of maximum slopes of volume and pressure pulses. The new calculation technique was applied to the same experimental data as it was used in our previous study. In this way, an influence of the changing pulse pressure on the results of different compliance estimates was assessed.

Methods

Subjects: A group of nine volunteers, four males and five females, aged from 29 to 58, were studied.

The study was approved by the Ethics Committee of the University of Tartu.

Experimental design: The subject was seated comfortably with both arms resting at heart level on the table. The left hand was used for measuring cardiovascular parameters. With the right hand the subject performed handgrip compression at the level of approximately 50 % of maximum voluntary contraction force. After an initial equilibrium period of 120 s, two successive one-minute handgrip compressions were conducted with a two-minute interval between them.

Beat-to-beat finger arterial pulse pressure: Beat-to-beat finger arterial blood pressure was measured by the Finapres 2300 BP monitor, Ohmeda, USA.

Finapres follows the idea of the volume clamp method (dynamic unloaded arterial wall principle) introduced by Peňáz [9]. Systolic (P_{syst}), diastolic (P_{diast}) and mean blood pressure (P_{mean}) values for every cardiac cycle are estimated from a full arterial pressure wave. The beat-to-beat finger arterial pulse pressure is calculated as difference $P_{pulse} = P_{syst} – P_{diast}$.

Beat-to-beat finger volumetric pulses: Beat-to-beat finger volumetric pulses were measured by the UT9201 physiograph, University of Tartu, Estonia. Originally constructed for finger mean blood pressure measurement [12-13], this instrument could also be used for recording pneumoplethysmographic (volumetric) pulses from two fingers. An advantage of this servo-based pneumoplethysmograph is that finger volumetric pulses ΔV are recorded at a fixed transmural pressure $P_{transm}= 0$. The volumetric pulses are picked up by two low-pressure electromanometers.

Finger cuffs of both instruments were placed on the fingers of the left hand. The fingers were carefully kept at the same level, equal to heart level.

Data processing: The analog signals from the Finapres and UT9201 instruments were digitised by an ADC (16-bit accuracy, sampling rate of 60 Hz) and transferred to the computer. Cardiosynchronised P_{mean} values were computed on-line by the numerical integration of the instantaneous blood pressure signal *P(t)*.

Two different estimates of the finger beat-to-beat compliance were used:

1) applying formula $C_1= \Delta V/\Delta P$, where ΔP is the finger arterial pulse pressure and ΔV is the corresponding pulsatile volumetric change. This methodology is commonly used by many investigators [2, 7] and was applyed by us in our previous study [11].
2) applying formula $C_2=dV/dP$, where dV/dP is the slope of the pressure-volume (*P-V*) relationship. We computed the slope from the first derivatives *dV/dt* and *dP/dt* of the recorded volume and pressure pulses near the point of their maximum slope. For more reliability, before dividing *dV/dt* by *dP/dt,* the derivatives were averaged over a moving window Δt=65 ms.

The measured volumetric pulses are in arbitrary units, and their scaling factors can be considered constant only during a single experimental session in one person. Measurement on another person may have a different scaling factor, thus making comparison between the individuals complicated. As we aimed to measure changes in the arterial compliance rather than absolute values, it is sufficient and reasonable to measure the volumetric signal in arbitrary units and express changes of compliance in relative units.

Comparison between the two calculation techniques for an estimation of the compliance can be assessed by dividing the values obtained by the 2nd technique, by values obtained by the 1st technique. This decision is based on the fact that both of the mentioned methods calculate beat-to-beat compliance from the simultaneously recorded pressure and volume waveforms, measured during a single experimental session in one person. In this way a normalization of the compliance signal was produced, and the compliance should have been regarded further as a relative variable.

For statistical analysis, episodes with the minimum pulse pressure during rest and with the maximum pulse pressure during handgrip were selected. In every selection readings over 3 successive cardiac pulses were averaged.

To test for the presence of significant differences, the Wilcoxon matched pairs signed rank test was used. A level of significance of 0.05 was applied.

Results

The obtained results revealed that, in general, there was a good agreement between the two beat-to-beat estimates of compliance when changes in the pulse pressure were smaller. Despite the non-uniform cardiovascular responses to handgrip exercise, the time courses of paired estimates had the same pattern, except episodes of large changes in the pulse pressure.

Figure 2 illustrates the character of different compliance estimates in patient D.

Table 1 summarises the group-averaged results. Compliance is expressed as a normalized variable (2^{nd} estimate /1^{st} estimate).

Discussion

Results show that evoked responses in different subjects were of different extent. This concerns changes in the finger mean blood pressure, volume and pressure pulses as well as compliance estimates. It is our opinion that obviously not all the volunteers followed an instruction of keeping the 50 per cent level from their maximum voluntary contraction force when performing the handgrip exercise.

Figure 2 illustrates the character of different compliance estimates in subject D. Before the physical exercise, beat-to-beat time courses of both estimates are close to each other. After an onset of the handgrip, the 1^{st} estimate monotonously falls down while the 2^{nd} estimate goes up. At the same time a considerable rise in the pulse pressure is observed.

It can be concluded, observing the S-shaped *P-V* relationship on Figure 1, that in case of $P_{transm}= 0$ an increase in the pulse pressure reduces the value of the 1^{st} (pulse amplitude based) estimate. Unlike the 1^{st} estimate, the 2^{nd} (slope-based) estimate is less sensitive to pulse pressure changes, assuming that the transmural pressure is automatically kept equal to 0.

The results of our study are in good agreement with the above-mentioned statement. In all the individuals, the ratio 2^{nd} estimate divided by the 1st estimate (Table 1) was higher for episodes with a high pulse pressure compared to episodes with a low pulse pressure. In other words, during handgrip exercise when pulse pressure goes up, the 1^{st} compliance estimate diminishes causing an increase in the ratio 2nd estimate /1st estimate.

Table 1 shows that the median pulse pressure change from 41 to 56 mm Hg is accompanied by a change in the ratio 2nd estimate /1st estimate from 1.06 to 1.15 (p<0.05). This means that a group-averaged pulse pressure change of 15 mm Hg caused an 8 % change in the pulse pressure based compliance estimate.

We conclude that the Finapres monitor combined with the UT9201 physiograph can be used in estimating rapid changes in the dynamic compliance of finger arteries. For better interpretation, a registration of slope-based beat-to-beat compliance is recommended instead of applying the pulse amplitude based estimation.

Conclusions

The results of the study demonstrate that even under the condition of fixed transmural pressure, the changing pulse pressure can affect readings of the beat-to-beat arterial compliance measurement when the pulse amplitude based estimation technique is applied. It was found that a group-averaged pulse pressure change of 15 mm Hg caused an 8 % change in this type of compliance estimate (p<0.05). The slope-based estimate of compliance is less sensitive to pulse pressure changes and can be preferred when considerable alterations in the amplitude of the arterial pulse pressure exist.

Acknowledgement

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Table 1. Comparison between group-averaged data of the two compliance estimates (1^{st} - pulse amplitude based; 2^{nd} - slope-based).

	2^{nd} estimate /1^{st} estimate	$P_{pulse\ min}$, mm Hg	2^{nd} estimate /1^{st} estimate	$P_{pulse\ max}$, mm Hg
1	2	3	4	5
Median	1.06	41	1.15	56
Range	1.01–1.18	36–47	1.02–1.21	46–73
			p<0.05, 4 vs 2	p<0.05, 5 vs 3

Significance of differences is tested by the Wilcoxon matched pairs test.

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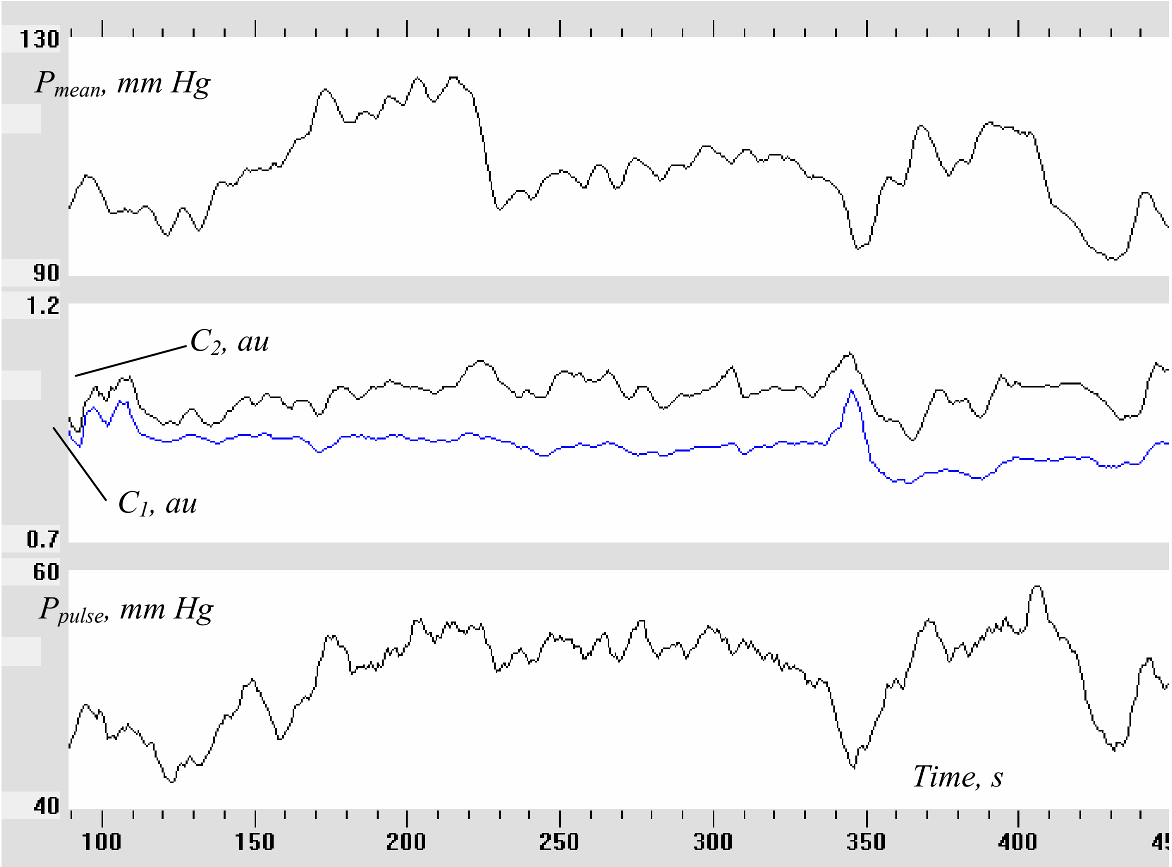

Figure 2: 6-minute beat-to-beat recording in subject D having different time courses of the compliance estimates during a great rise in the pulse pressure. Finger mean blood pressure (P_{mean}), pulse pressure (P_{pulse}), 1st estimate of the beat-to-beat compliance (C_1) and 2nd estimate (C_2) are shown. Pressure signals are in mm Hg, compliance signals in arbitrary units.

The handgrip exercise started at 120 s.

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