

# Methodological aspects in the measurement of pulse wave velocity by means of applanation tonometry

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See original paper on page 117

Pulse wave velocity (PWV) is a simple, noninvasive, reliable and reproducible marker of the viscoelastic properties of an arterial segment and, therefore, of arterial stiffness [1,2]. Several epidemiological studies have shown the predictive value of aortic PWV (aPWV) for cardiovascular diseases, over and above the contribution by other major risk factors [3–6]. Transcutaneous measurement of carotid-femoral PWV has been shown to reliably reflect PWV values obtained directly in aorta [7], the accuracy of such a measurement being an essential requirement for a correct evaluation of the contribution of PWV to cardiovascular risk.

Carotid-femoral PWV is determined from the time taken by the blood pressure wave to propagate from the carotid to the femoral artery. Aortic PWV is defined as the ratio of the distance between the two locations on which blood pressure wave is measured (the common carotid and the femoral artery) to the time delay of the femoral blood pressure wave in relation to the carotid blood pressure wave. Several techniques have been developed for measurement of PWV, either in relation to the measurement of the distance between the two arterial sites and in relation to the assessment of pulse pressure wave transit time. Given that there are different methods for PWV assessment available in the market, the number of which is continuously increasing, physicians and researchers can be bewildered by the absence of a standard approach recommended worldwide. With such a background, several efforts have been made to establish uniform and widely accepted principles for the measurement of PWV.

In particular, the problem of how to best measure the distance between arterial sites for the assessment of PWV has been repeatedly addressed. In an expert consensus document by van Bortel *et al.* [8], recommendations for the

evaluation of such a distance have been recently provided, aimed at standardizing the assessment of aortic stiffness in daily practice. In this document it was agreed that the tape measure of the direct straight distance between the two measurement sites, and use of 80% of this distance as pulse wave travelled distance, should be considered as the most accurate approach to the measurement of the distance between the carotid and the femoral sites, where probes have to be positioned [8].

Currently, several different techniques are also being used for the assessment of pulse pressure wave transit time. The difference between these techniques depends on a number of factors (Box 1). First, it depends on the technology used for recording pulse waves (based on applanation tonometry, ultrasound systems, oscillometric methods or piezoelectric mechanotransducers, respectively). Second, it depends on the different algorithms used for the calculation of pulse pressure wave transit time:

#### Box 1 Different methodological approaches to measure aortic pulse wave velocity

##### Procedure for assessment of PWV

- One-shot mode: carotid and femoral pressure waves recorded simultaneously.
- Sequential mode: carotid and femoral pressure waves recorded sequentially, taking the R wave of the ECG as reference point.

##### Types of probes and sensors available for recording pulse waves

- applanation tonometry,
- ultrasound systems,
- oscillometric methods,
- piezoelectric mechanotransducers.

##### Measurement of the distance between arterial sites

- 80% of direct carotid-to-femoral distance (recommended),
- direct carotid-to-femoral distance,
- 'subtractive' method: using the length obtained by subtracting the distance between the suprasternal notch to the carotid site from main path length (e.g., suprasternum-femoral or carotid-femoral) in an attempt to account for the opposite pulse transition toward the carotid artery.

##### Algorithm used for assessing pulse wave time delay

- foot-to-foot method,
- superimposition of carotid and femoral waves,
- use of the derivatives of pulse waves.

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foot-to-foot method, which uses the foot of the wave as reference point; superimposition of carotid and femoral waves; use of the derivatives of pulse waves, and so on.

The study by Dzeko *et al.* [9], published in this issue of the *Journal of Hypertension*, represents an attempt to optimize the standardization of the methodology for PWV assessment, aimed at further improving its accuracy and thus at bringing this indirect measure as near as possible to the real PWV value. The efforts made by Dzeko *et al.* [9] to optimize the accuracy of PWV measurement have in principle to be acknowledged and appreciated, in a time when manufacturers of devices for the assessment of arterial wall properties tend sometimes to sacrifice accuracy to simplicity of use and operator-independent performance.

Dzeko *et al.* [9], on the background of current recommendations to use the right carotid artery for PWV assessment [1], have in particular focused on the comparison of PWV measures obtained, in the same patients, by using the right or the left carotid artery, respectively, and have in addition compared the data obtained by two different observers. The results of their study show that use of the right carotid artery overall provided 'significantly' higher aPWV values compared with use of the left carotid artery ( $6.5 \pm 1.2$  m/s with right carotid artery versus  $6.4 \pm 1.1$  m/s with left carotid artery,  $P=0.003$ ). The average difference between the two approaches, by considering data from both observers together, was  $0.2 \pm 0.4$  m/s. Based on these results, the authors concluded that aPWV should be measured on the right common carotid, as recommended by guidelines [1].

These conclusions, however, need to be taken with some caution. By carefully reading this article, it becomes apparent that the difference in PWV between the two carotid arteries was somehow operator-dependent, being less marked with observer 1 ( $0.1 \pm 0.4$  m/s,  $P=0.05$ ) than with observer 2 ( $0.2 \pm 0.6$  m/s,  $P=0.009$ ). In the same study, the two observers provided significantly different values of PWV independently of the choice of right or left carotid artery for its assessment. Indeed, observer 1 always obtained significantly lower aPWV values than observer 2 ( $6.4 \pm 1.2$  m/s versus  $6.7 \pm 1.3$  m/s using right carotid artery,  $P=0.02$ , and  $6.3 \pm 1.1$  m/s versus  $6.4 \pm 1.2$  m/s, NS, using left carotid artery,  $P=0.13$ ), with an average between-operator difference of 0.3 m/s, that is a difference larger than the overall difference found between use of the right or left carotid artery. Moreover, the mean aPWV values obtained from observer 1 on right carotid artery were superimposable to those obtained from observer 2 on left carotid artery. Thus, such a difference between aPWV values measured by the two operators may undermine the general conclusions of this study in favor of using the right carotid artery in this context.

In fact, the significant differences between aPWV assessed on the right or on the left carotid artery, and those between measurements performed by operator 1 or operator 2, taken together suggest that the problem might not be related to 'where' the measurements is taken or by 'whom'. It should rather be acknowledged that the measurement of PWV is characterized by a remarkable physiological variability, which seems to be a characteristic feature of the methodology itself.

This variability is the result of the action of functional factors, which can affect the mechanical properties of large arteries such as heart rate, endoluminal pressure, the smooth muscle tone of arterial wall and the systolic ejection timing of the left ventricle. Moreover, conditions characterized by high variability in blood pressure are also contributing to the variability in PWV values [10]. These factors, responsible for the occurrence of continuous oscillations in PWV values, cannot be easily controlled when arterial properties are being tested in the vascular laboratory. However, they must be taken into account when interpreting the data recorded. Moreover, in order to reduce the impact of these factors on PWV instability, it is strongly recommended, both in a clinical setting and in research, to adjust PWV values for mean arterial pressure and heart rate.

Assessment of PWV could be further improved by carefully considering other methodological aspects related to the way pulse pressure waves are recorded. In particular, it is very important to take care of how an assessment of arterial wall properties is carried out when using applanation tonometry. The tonometer is an instrument that is easy to use but also extremely sensitive, not only to the pressure exerted on the artery to be explored, but also to the involuntary movements made both by the operator and by the patient. The presence of these movements makes the recording of pressure waveform importantly affected by 'noise', which can make the correct identification of both the foot of the blood pressure wave and of transit time a difficult task. It is therefore very important to reduce the presence of these 'noise' factors to a minimum.

Some practical advice to help removing the 'noise' coming from these undesirable movements are shown in Figure 1.

A good recording, without any artefactual movement, is essential to obtain valid transit time and valid PWV values. When recording blood pressure waveforms by means of tonometry, therefore, priority must be given to the quality of the tracing being recorded. In fact, whenever the tonometric test is accurately carried out, the variability in results associated with the operator performance can be reduced to a minimum. Based on these considerations, it is easy to understand that, in spite of the general recommendation to use the right carotid artery for PWV assessment, a left-handed operator should better carry out the test on the left carotid artery, as the approach to the left side of the neck is easier and characterized by a better performance in such a case.

The investigation by Dzeko *et al.* [9] has emphasized the fact that differences between the data acquisition on left carotid with respect to the right carotid artery are overall of small entity. This applies, however, to high quality recordings. On the contrary, a pulse pressure waveform, which is incorrectly recorded or is affected by artefactual movements could easily lead to unreliable PWV values. Given the practical relevance of these methodological issues, further investigations are still needed in this context, similar to the one carried out by Dzeko *et al.* [9], with the aim of providing tools and suggestions to improve the reliability and accuracy of PWV values recorded through a tonometric approach.

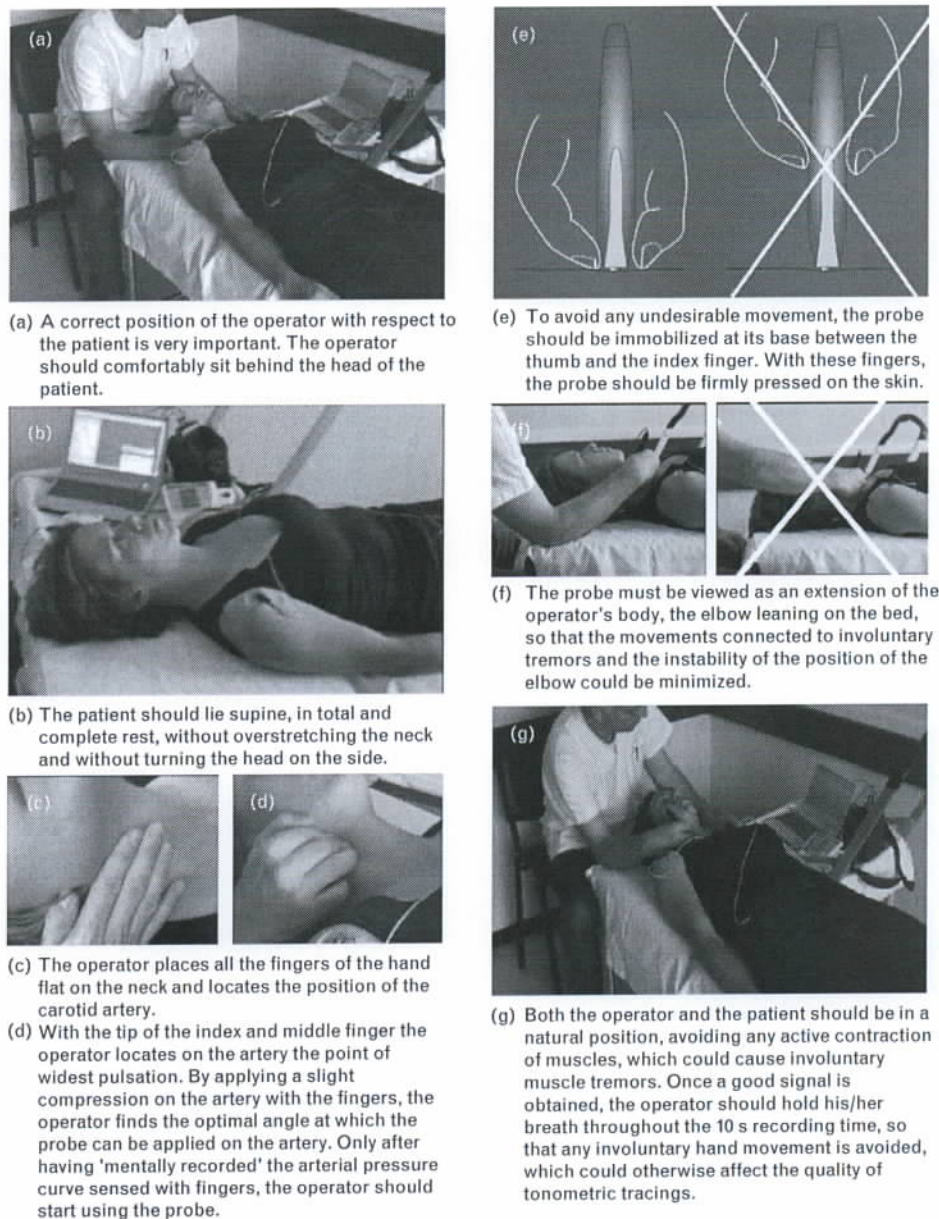


FIGURE 1 Practical recommendations for the assessment of carotid pulse waves by means of applanation tonometry.

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**Conflicts of interest**

P.S. is consultant for DiaTecne s.r.l., manufacturer of a pulse wave analysis system.

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