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COMMENTARY

Noninvasive estimation of central blood pressure and analysis of pulse waves by applanation tonometry

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Arterial pulse recording and pulse waveform analysis have represented a goal for physicians and experimental physiologists since the second half of the nineteenth century. Sphygmographs, developed by pioneers such as Marey (1830–1904), Landois (1837–1902) and Mahomed (1849–1884), allowed radial pressure wave recording on paper. Diagnostic hypotheses concerning cardiovascular function were derived from the analysis of these recorded pulse waveforms. Since then, radial pulse wave recording has found a place among classic cardiovascular diagnostic examinations. At the end of the twentieth century, however, the introduction of the arm cuff sphygmomanometer and the perspectives raised by its clinical application led to a decline in interest in pulse wave recording and analysis. Indeed, throughout the last century, the ability to easily measure systolic and diastolic blood pressure, that is, the zenith and the nadir, respectively, of the pulse wave, made pulse wave recording obsolete in clinical settings. Blood pressure measurement with the arm cuff sphygmomanometer has changed the clinical history of cardiovascular diseases by highlighting the importance of hypertension as a cardiovascular risk factor and by significantly reducing cardiovascular morbidity and mortality by enabling better control of high blood pressure.

When the registration of pulse waves became technically possible by invasive catheterization, the interest of physiologists and interventional cardiologists in pressure wave morphologies, particularly for aortic blood pressure measurements, was renewed. The subsequent availability of transcutaneous tonometers able to measure pressure waveforms noninvasively led to in-depth studies on the role of the mechanics of large arteries in the pathophysiology of arterial hypertension and made performing large cohort clinical trials possible.

Arterial tonometry is based on the principle of applanation tonometry, and it enables the assessment of arterial districts, in which an artery runs superficially and may be compressed against underlying structures (that is, carotid, brachial, radial, femoral, posterior tibial and dorsalis pedis arteries). A tonometric pulse wave recording is a well-tolerated, reproducible, fast and noninvasive test. A few studies have clearly shown that arterial pressure waveforms recorded noninvasively by transcutaneous tonometry are largely superimposable over those recorded invasively with an intra-arterial catheter.[1,2]

The main limitation of applanation tonometry is its inability to provide absolute values of arterial pressure. A tonometer is able to define pulse pressure values, but it is unable to provide accurate values for diastolic and systolic blood pressure. Thus, calibrating a tonometric pressure wave with brachial arterial pressure values is always required, particularly when estimating central blood pressure by analysis of peripheral pulse waves.

There are two methods, both of which are well validated and reliable, to record central pressure waves by arterial tonometry: the 'direct method' and the 'indirect method'.[3]

(1) In the 'direct method', the recording of a pulse wave in the common carotid artery is used as a surrogate for aortic pressure because of the proximity of these arterial sites. Many studies have shown that the shape of the pressure wave in the ascending aorta is similar to the one recorded in the common carotid artery. Therefore, a direct application of tonometry on the carotid artery seems to be an easy and reproducible approach for recording central blood pressure. Moreover, the carotid artery is generally well accessible and superficial (Figure 1, upper panel). This method is used by the PulsePen device (DiaTecne, Milan, Italy).[1]
(2) In the 'indirect method', a central pressure waveform is rebuilt starting from the waveform recorded by tonometry in the radial artery, through a generalized transfer function (Figure 1, lower panel). The indirect method is used by the SphygmoCor (AtCor Medical, Sydney, NSW, Australia). A similar system is in place in the Omron HEM-9000AI (Omron Healthcare, Kyoto, Japan),[4] which uses linear regression models that rely on the correlation between the second systolic peak of the radial pressure waveform and the central systolic blood pressure to estimate central pressure.

Although brachial blood pressure is only a surrogate for aortic pressure, and central blood pressure measurement can now be indirectly estimated easily and noninvasively, the latter approach is not currently proposed as a replacement for brachial blood pressure in clinical settings. The theoretical interest in

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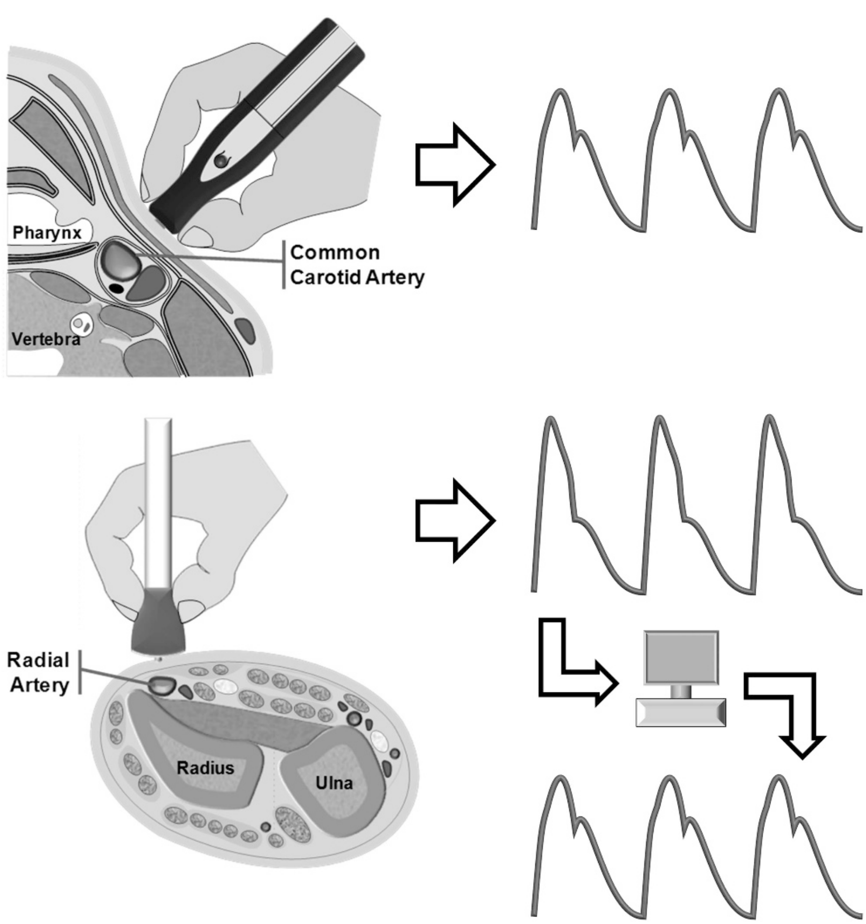

Figure 1 Methods for assessing central blood pressure and pulse wave analysis with arterial tonometry. Upper panel: central blood pressure waveform is recorded at the carotid artery level ('direct method'). Lower panel: arterial pulse wave is recorded at the radial artery level, after which software rebuilds the corresponding central pulse waveform and provides central blood pressure values ('indirect method').

central blood pressure measurements arises from the assumption that central systolic blood pressure and central pulse pressure should be much better than peripheral systolic blood pressure and peripheral pulse pressure for estimating the real load imposed on the left ventricle. Clear evidence demonstrating a stronger relation of central rather than peripheral pressure with cardiovascular events and mortality is now emerging.[5–7] However, whether risk stratification is more precise when based on central rather than on peripheral blood pressure has not yet been definitively established.

In recent years, greater attention has been paid to pulse wave analysis as a means of obtaining additional information beyond central blood pressure estimates. The potential clinical relevance of variables such as augmentation index, blood pressure amplification and subendocardial viability ratio has been increasingly acknowledged in recent years. However, although they are frequently used in research settings, these variables have not yet achieved widespread use in clinical practice.

In fact, despite increasing evidence supporting the value of central blood pressure measurement and pulse wave analysis, such assessments are not yet recommended in routine clinical use.[8] However, arterial tonometry allows in-depth diagnostic evaluation, particularly in conditions in which an accurate assessment of central pulse wave analysis is requested. The goal of an in-depth evaluation is to obtain an indirect study of left-ventricular myocardial function or heart work. The recent guidelines for the management of arterial hypertension by the European Society of Hypertension and the European Society of Cardiology, despite acknowledging the role of carotid-femoral pulse wave velocity as a marker of vascular organ damage in hypertension, recommend the measurement of central blood pressure only in individuals with isolated systolic hypertension.[8] In fact, in some of these individuals, increased systolic blood pressure at the brachial level may be due to excessive amplification of the central pressure wave despite normal central blood pressure.

To promote a wider and more appropriate use of central blood pressure assessment, it is very important that central blood pressure values estimated by arterial tonometry be reliable and that the parameters relative to the central arterial pressure waveform closely correspond to those recorded in the ascending aorta. Thus, any attempt to improve the methodology of central pulse pressure estimation will be more than welcome.

The study by Martin *et al.*[9] explores unresolved methodological issues related to central blood pressure assessment. Despite an extensive debate regarding the most appropriate method for central blood pressure measurement, this study sought to answer common methodological questions related to the indirect method commonly used to derive aortic pressure estimates from radial artery pressure waveform, which has been the most used methodology to date.

The first question is about the effect of homolateral brachial artery sphygmomanometry on subsequent pulse wave analysis. In this study, there were no differences in left radial pressure pulse waveforms between the recordings performed before and after a brachial sphygmomanometer measurement in the same arm. For the right arm, small differences in pulse wave analysis variables were present with consecutive radial tonometric measurements surrounding the peripheral blood pressure assessment. Despite these results, a cautious approach should be taken when performing peripheral artery tonometry. Given the known endothelial effects in the distal artery induced by cuff inflation and transient interruption of blood flow, waiting 2 min after peripheral blood pressure measurement before performing radial tonometry is appropriate whenever possible.

Selection of the limb on which to perform pulse waveform analysis is the other major topic in this study. A significant difference in peripheral blood pressure between arms was found in 26.5% of healthy subjects in well-standardized conditions. These data agree with those reported in previous papers.[10] In both clinical and research settings, differences in blood pressure values between arms are often ignored in applanation tonometry, and this may cause some measurement errors. The authors demonstrate that using either left or right peripheral blood pressure for calibration generates significant differences in variables derived from radial pulse wave analysis. In addition, a within-arm calibration is mandatory to ensure correct measurements whenever accurate estimates of central blood pressure and pulse wave analysis-derived variables are needed, that is, for research purposes. The use of the higher observed blood pressure between arms would be a more realistic solution in a clinical setting to avoid underestimation of blood pressure. A valuable recommendation from this study is that performing a bilateral blood pressure measurement is imperative before performing peripheral tonometry. Otherwise, a significant increase in the variability of measurements derived from pulse wave analysis would be introduced. Moreover, the authors found a greater variability of pulse wave analysis-derived indices in the right radial artery. Therefore, they suggest performing SphygmoCor tonometry in the left arm rather than in the right one. However, only a small number of young individuals were recruited in this study, too few to allow robust methodological recommendations that could be applied in everyday practice to be made. Therefore, as the authors correctly acknowledge, these results would need to be confirmed by replicating a similar study with a larger and more heterogeneous population.

The study by Martin *et al.*[9] may be useful in improving the indirect method used to assess central blood pressure (SphygmoCor and Omron HEM-9000AI devices) by providing important methodological suggestions. However, it highlights further limitations in the methods in which a central pressure waveform is acquired starting from radial artery tonometry.

A greater degree of variability in measures could be a significant issue in clinical trials, in which replicable and accurate results are pursued. However, the major limitation of central blood pressure assessment by applanation tonometry by the indirect method is the calibration of pulse waves. The results of the Asklepios Study showed significant differences between pulse pressure (and systolic blood pressure) values assessed in the brachial artery and those obtained in the radial artery. These differences were much greater than the differences between central arterial pressure and the brachial arterial pressure.[11] In other words, pulse pressure amplification is more marked in the brachio-radial arterial segment than in the aortic-axillo-brachial one. If a peripheral waveform is calibrated to brachial systolic and diastolic cuff pressure values, given the above-mentioned differences between blood pressure parameters derived from different arterial segments, such a procedure might introduce relevant errors in the estimation of central blood pressure. Thus, as a general consideration, caution is needed whenever using algorithms for central pressure estimation based on measurement of pressure values in the brachial artery to calibrate a pressure wave recorded in the radial artery.

In summary, the study by Martin *et al.*[9] published in this issue of *Hypertension Research* may help to improve the methodology of pulse wave analysis based on arterial tonometry. However, when considering the use of tonometric assessment of the pulse waveform from a radial artery site, further studies will be needed to solve the major limitation of this method, that is, the current approach to radial waveform calibration through blood pressure measurements performed at a brachial artery level.

CONFLICT OF INTEREST

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