Editorial Commentary

Pulse Waveform Analysis and Arterial Wall Properties

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Risk factors for cardiovascular disease mediate their effects by altering the structure, properties, and function of wall and endothelial components of arterial blood vessels.[1] The ability to detect and monitor change in the physical properties of arteries, representative of the cumulative and integrated influence of hemodynamic, metabolic, and inflammatory stimuli in impairing arterial wall integrity, holds potential to intervene at a preclinical stage to prevent or attenuate disease progression. The importance of assessing arterial wall integrity has been highlighted by recent studies demonstrating that a decrease in the pulsatile function of large arteries represents an independent predictor for future cardiovascular events.[2]

Information about the interaction between the left ventricle and the physical properties of the arterial circulation can be derived by the descriptive and quantitative analysis of the arterial pressure pulse waveform.[3] Consistent characteristic changes in the pressure pulse waveshape have been described with aging and disease states predisposing to an increase in vascular events. One such age-related change involves a steepening of the pressure decay in diastole, largely determined by impaired buffering function of the proximal aorta.[3,4] Loss of the oscillatory waveform that distorts the proximal portion of diastole from a pure exponential represents a further early and consistent finding with aging and risk factors for cardiovascular disease including hypertension, smoking, and diabetes mellitus.[3–7] This feature arises from reflection of the incident pressure wave generated by the left ventricle from peripheral reflecting sites with a major contribution originating from impedance mismatches in small arteries and arterioles. The progressive appearance of the reflected wave in systole and eventual summation with the forward incident wave results in augmentation of the systolic blood pressure. Given the proximity of the central aorta to the major peripheral reflecting sites in the lower limbs, augmentation of the systolic blood pressure occurs in this vessel before changes are recorded in the upper limb vessels. Recently, techniques based on the determination of a pressure transfer function between the radial artery and the aorta have been employed to provide an estimate of central pressure wave reflection.[8]

In this issue of *Hypertension*, Millasseau et al[9] report on the accuracy of employing a generalized transfer function to the radial artery pressure pulse waveform to provide an estimate of the aortic augmentation index. The accuracy of the approach was assessed against data derived directly from the carotid pressure pulse waveform or after application of a transfer function to the waveform. The authors confirm prior observations that indicate the use of a general transfer function can show a considerable amount of bias and variation that limits the utility of this approach in accurately predicting the central augmentation index.[10,11] Further support for this contention is provided by a recent study where simultaneous recordings of invasive central aortic and noninvasive radial blood pressure waveforms were made in 78 subjects.[12] Values for the augmentation index, derived using transfer functions applied to the radial waveforms, were significantly different from directly measured values, and no correlation was evident between the 2 estimates. However, as the radial artery pressure pulse waveform contains all the information required to synthesize a central pressure waveform; similar information relating to pressure pulse wave reflection in the arterial circulation may be derived directly from the peripheral waveform without resorting to the use of a transfer function. Millasseau et al show a simple method for estimating the radial augmentation index to provide information about pressure pulse wave reflection in the arterial system. An important issue relates to how information provided by detecting and tracking this marker of wave reflection is interpreted in relation to the status of the arterial vasculature and the hemodynamic actions of drug interventions.

The determinants influencing wave reflection in the arterial circulation comprise the pattern of left ventricular ejection in addition to the magnitude and timing of reflected waves from peripheral reflecting sites in the arterial vasculature.[9] Assessing the effects of wave reflection in altering the pressure pulse waveshape has proven valuable in marking altered structure or tone in the vasculature and is a sensitive tool for studying the hemodynamic actions of drug interventions.[3,13] For example, nitroglycerin administration produces marked changes in the pressure pulse waveshape, which can be dissociated from a change in total peripheral resistance or the pulse transit time measured by aortic pulse wave velocity.[14,15] The effects are explained by changes in the mechanical properties of peripheral muscular arteries that result in improved impedance matching and attenuation of wave reflection in response to nitroglycerin. Direct ultrasonic techniques employed to assess local wall properties of peripheral muscular arteries indicate that arterial compliance (a property that depends on arterial geometry and intrinsic vessel wall properties) improves consistently, whereas distensibility (an intrinsic property of the arterial wall materials) does not necessarily change in response to nitroglycerin administration.[16] The nature and magnitude of change in the derived measures are sensitive to various confounding influences, which can be independent of

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a change in the physical properties of the circulation. Clearly, descriptive analysis can be employed to monitor the influence of wave reflection in altering the arterial pressure pulse waveshape, but attributing alterations in the arterial waveshape to a specific mechanical descriptor representative of the physical properties of arteries is more problematic.

A number of investigators unequivocally relate a change in the augmentation index, described in association with aging and disease states, to altered stiffness of the arterial vasculature.[17,18] Because no direct measurement of the mechanical properties of arteries is employed, relating a waveshape change to alteration in the physical properties of arteries must be regarded as speculative. A number of variables, including age, gender, height, heart rate, and blood pressure represent confounding influences that show an association, at least in some studies, with the derived augmentation index.[12,19] Furthermore, arterial stiffness is a generic term, without precise definition, which has no mathematical relationship to the mechanical properties of arteries and therefore cannot be measured or quantified.[20] Foot-to-foot pulse wave velocity provides an estimate of the transit time delay for a pressure or flow waveform to travel over a known distance. Changes in this measurement have also become synonymous with altered stiffness of the arterial segment under study.[3,20] Simultaneous assessment of the augmentation index and aortic pulse wave velocity reveals a positive but modest correlation ($r=0.29$).[21] In this study only 9% of the variation in pulse wave velocity was explained or accounted for by variation in the augmentation index. Determination of the augmentation index and pulse wave velocity represent indirect approaches that furnish different information on the status of different sections of the arterial circulation. The approaches provide no information about arterial stiffness, a parameter that defies characterization, and it is misleading and confusing to employ this descriptor to link changes in the measures with altered mechanical properties of arteries. Quantitative relationships between changes in the arterial pressure pulse morphology and mechanical properties of arteries can only be derived using interpretative models of the circulation.[3] However, this indirect approach also has limitations and the derived relationships cannot represent a complete description of physical phenomena occurring in the arterial system.

There is no doubt that analysis of the arterial pressure pulse waveform provides information about the interaction between the heart and the peripheral vasculature beyond that provided by clinic-based blood pressure measurement. Technological advances now permit the noninvasive acquisition of pressure pulse waveforms in a repeatable and reproducible fashion. That early and consistent changes in the pulse contour occur with aging and cardiovascular risk factors suggests that descriptive analysis of the pulse contour may hold potential to refine cardiovascular risk stratification and guide therapeutic interventions. The factors that determine the magnitude and pattern of wave reflection are diverse, interact in a complex fashion, and may be independent of a change in the mechanical properties of arteries. No single mechanical descriptor can account for alterations in the pressure pulse waveshape, which represents a global manifestation of age and disease-related changes in pulsatile and steady-stage hemodynamics that vary throughout different sections of the arterial vasculature.

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