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COMMENTARY

Assessment of central blood pressure waveforms—let the buyer beware: different approaches result in different results

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In this issue of the journal, Rezai *et al.*[1] have provided a very thorough empirical analysis of the critical influence and importance of calibration methods on the non-invasive determination of central blood pressure (BP). It is well known that the underlying assumptions applied and the accuracy of any calibration method used are the major limiting features in defining the precision of non-invasive assessment of arterial BP.[2,3] The type of work they report is absolutely critical to the appropriate application of the burgeoning number of commercial devices now available to 'calculate,' 'infer' or 'estimate' central BP from peripheral recordings.

It is accepted that knowledge of central (that is, aortic root) BP could be a useful clinical sign influencing cardiovascular prognosis and particularly in effecting optimal management; however, a number of critical issues immediately arise as follows:

1. For useful application, any method must be non-invasive, quick, relatively easily learned and reproducible.
2. The result of assessment should ideally be interchangeable, that is, not device specific. A corollary of this is that if the central BP or other waveform parameters determined by available methods were in fact equally accurate, any discussion of methods would be irrelevant, and the considerable literature on the subject of validity and comparison superfluous. It is obviously not the case that all devices available for use afford the same result, nor, importantly, do they purport to, so the critical issue must be addressed as to which (if any) approaches are accurate or superior, raising issues associated with (a) the appropriateness of comparison within and between results and (b) justification of the underlying assumptions and of the computational approaches taken with particular devices.

It will obviously be a very severe limitation to the clinical use of central BP and associated parameters if there is a lack of interchangeability of assessment (that is, if one practitioner uses one system there may be no comparability if the patient is then required to consult another practitioner who chooses to use a different system, albeit purporting to report the same parameter).

The work by Rezai *et al.*[1] highlights some of the major issues currently hindering the general application of central BP waveform assessment, namely calibration errors, either systematic or random (probably both). Potentially, even more significant issues also raised by their report are the different internal, and poorly acknowledged, assumptions made within the different technical approaches, including in the internal steps (validated or not) used to derive the final parameters supplied to the user in a more or less sophisticated form.

The internal methodologies incorporated into the various systems are poorly known and understood. Despite considerable discussion within expert circles, it is very likely that the potential 'average user' of this type of technology may assume applicability and accuracy beyond that which has been established. To this end, Rezai *et al.*[1] also emphasize design differences in the devices they compared, a very useful addition indeed to the available literature.

It is worth specifically comparing summaries of the devices provided by Rezai *et al.*,[1] which provide a reasonably thorough review of the differences between systems. These differences include:

1. Use of either proprietary transfer functions or regression/correlation algorithms
2. Radial or brachial tonometry
3. Different (and site specific) formulae to calculate augmentation index
4. Use of radial and/or brachial and/or central augmentation index
5. The issue of assigning brachial peak and trough BP values to radial waveforms

There are also potential errors introduced by use of the standard assumption of uniformity of mean BP and diastolic BP in the conduit arteries, as well as by the means of non-invasive assessment of mean BP. Rezai *et al.*[1] also discuss these issues.

The majority of early work carried out on this topic relied on the 'one-third' rule, that is, mean BP=diastolic BP+1/3 (pulse pressure), which requires accurate measurement of both diastolic BP and SBP using conventional means. Rezai *et al.*[1] also invoke an expression for mean BP using a form factor of 0.4 on the pulse pressure. These formulae themselves are interesting, with the 1/3 rule relying on the well-known expression for the center of area of a triangle, justified by approximating the aortic pressure wave as approaching a triangle superimposed on a rectangle (see Figure 1). The 0.4 factor is based on invasive work[2] suggesting a difference of ~4–5 mmHg (higher) in mean BP,

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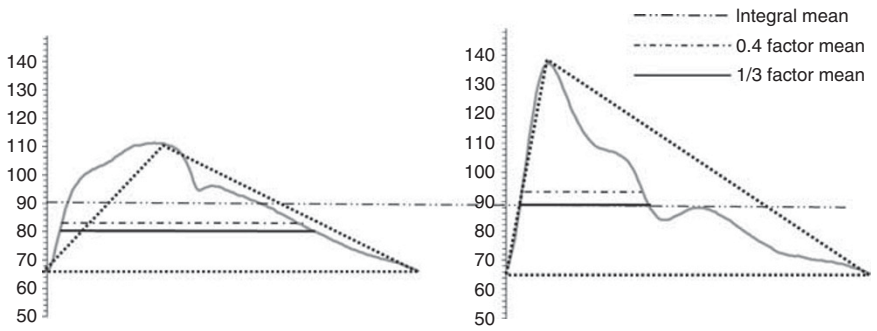

Figure 1 Schematic illustration of differences in scaling procedures. Figure shows non-invasively (tonometer) BP waveforms obtained simultaneously from the right carotid artery and the right radial artery.[7] Both waveforms were scaled to the brachial measured DBP and integral mean $\bar{P} = \frac{1}{T}\int P(t)\,dt$ of the waveforms (–·–·–·–). The solid line (————) represents the estimated mean using the one-third formula with the dashed/dotted line (–··–··–··–) representing the estimated mean using the 0.4 factor. A full color version of this figure is available at the *Hypertension Research* journal online.

which is in fact consistent with a more rounded pulse pressure waveform moving the center of area higher.

It has long been stated that a consequence of aging and increased conduit artery stiffness is a more peaked (that is, more triangular) pressure waveform morphology, consistent with the 1/3 approach being perhaps more applicable in the elderly or in conditions of increased arterial stiffness (for example, renal disease or CVD, in which most of the early and invasive studies were performed). In such situations, there is generally considered to be little difference between radial/brachial and central systolic BP.

It is an interesting, but not discussed,[1] observation that the differences between SphygmoCor and other devices were associated with higher HR, MAP and height, factors presumably involved in the inbuilt regression derivations of other devices but were not taken into account in the transfer functions approach. Also interesting in view of their careful methodology is the authors' finding of little (Arteriograph) or no (Omron) difference between central systolic BP and brachial BP, which obviously questions the relevance of estimating central systolic BP at all. This finding is in fact similar to at least two previous reports not referenced.[4,5]

The ever-increasing number of devices and systems available to estimate central BP waveforms in clinical practice is concerning, particularly in the context of the establishment of normal values and for the comparison of results. The recent establishment of 'normal and reference values' for pulse wave velocity[6] is an example of the issues about to be faced in the assessment of central BP. The lack of agreed standardization of technique for measuring pulse wave velocity, inherently a much simpler process than estimating central BP, illustrates the problem well. In establishing norms of pulse wave velocity, there were problems with a lack of uniformity in defining path length, in methods of detection of the 'foot' of the pressure waveform and in estimation of true, as opposed to externally measured, path length. These issues resulted in the need for at least three different regression relationships to allow the interconversion of techniques and the comparison or pooling of results,[6] an inferior approach compared with adopting standard measurement techniques. Although mandated by a contemporary lack of advanced technology at its inception, and certainly not error free, the standard brachial BP method proposed by Riva Rocci was based on fundamental physical principles (for example, the height of a column of mercury) and did not involve the introduction of further computational assumptions and potential inaccuracies.

The report by Rezai *et al.*[1] in this issue is notable for at least two significant reasons as follows:

1. It is the first to thoroughly and comparatively discuss the issues of calibration and underlying assumptions and to reasonably compare and highlight the differences in the available techniques.
2. It highlights for the user the multiple assumptions and proprietary approaches that are involved in all the available devices.

With due consideration and knowledge of the issues described by Rezai *et al.*[1] and consideration at an individual patient level, physicians using the available systems can make a reasoned decision. What is equally important is that as new commercial devices appear (which is inevitable), that the same scrutiny is invoked and that generic 'substantial equivalence' does not provide new approaches with easy and inadequately validated acceptance into clinical use. Rezai *et al.*[1] have clearly shown that there is more in these 'black boxes' than may meet the eye.

In this commentary, I have tried to point out that there are multiple steps and assumptions in any of the methods of non-invasive estimation of central BP. Each step potentially involves multiple assumptions and multiple sources of error—due to both incorrect biological assumptions and/or to systematic and random measurement error.

The other issue raised is the perennial one of group versus individual accuracy. That group results, however calculated, and however accurate relate to each other does not address the issue of applicability for individual use. This issue can only be assessed from large outcome trials using derived central BP indices as treatment goals—for this to be useful, a single technique is required as attempts at interchangeability or of pooling results from multiple techniques would only introduce further approximations and errors in recorded values.

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