Central Blood Pressure: To the heart of the matter

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Outline of Lecture

• What do we mean by Central Aortic Pressure?
• How do we measure Central Aortic Pressure?
• What is the relationship between aortic systolic and brachial systolic pressures?
• What is a normal aortic systolic pressure?
• Central Aortic Systolic Pressure: The new BP target?
A new sphygmomanometer
A report by Dr Scipione Riva-Rocci*
Blood Pressure Measurement
Changing trends?

• Brachial BP predicts risk because it is a surrogate for pressure in the large arteries and vital organs;

• But...is brachial BP always the perfect surrogate for pressure in the large arteries?

• If we could do it, would “measurement” of central aortic pressure provide a more accurate estimate of cardiovascular risk and treatment efficacy?
Central Aortic Pressure versus Brachial Pressure

- Diastolic pressure remains relatively constant across the large arteries;
- Systolic pressure is amplified from the aortic root to the periphery;
- The relationship between brachial and central aortic pressure is modified by ageing, disease and drug therapy;
- So,..brachial pressure is not always a perfect surrogate for central aortic pressure;
The Non-Invasive Measurement of Central Aortic Pressure: Pulse Wave Analysis
Common Methods for Non-Invasive Measurement of Central Aortic Pressures and Haemodynamics

• Radial artery pulse wave analysis via tonometry – calibrated to brachial blood pressure – use of mathematical modelling to derive central aortic pressures;

• Carotid artery tonometry directly calibrated to brachial blood pressure;
Deriving Central Aortic Pressure from the Radial Pulse Wave

Mathematical Conversion

Radial pressure wave

Central Aortic pressure wave
Methods for Deriving Central Aortic pressures from the Radial Artery Pressure Wave form

• Generalised Transfer Function to synthesis a central aortic pressure wave form and derive central aortic pressure indices;

• Estimation of radial pressure wave inflection point – SBP2;

• Use of an N-point moving average method (NpMA).
An analysis of the relationship between central aortic and peripheral upper limb pressure waves in man

M. KARAMANOGLU*, M. F. O’ROURKE†, A. P. AVOLIO* and R. P. KELLY†

*Centre for Biomedical Engineering, University of New South Wales, †Medical Professorial Unit and Cardiology Department, St Vincent’s Hospital, Sydney, Australia

Cardiac catheter direct measurement of central aortic systolic pressure versus GTF-derived aortic systolic pressure using PWA (N = 14)
A novel method to directly derive central aortic systolic pressure (CASP) from the radial artery pressure waveform: Using an N-point Moving Average

Williams B*, Yan P, Lacy PS*. Ting C.M., Chua N.H. & Chen L.
Department of Cardiovascular Sciences & NIHR Cardiovascular Biomedical Research Unit, University of Leicester School of Medicine, UK*, Gleneagles Medical Centre, & Healthstats International, Singapore.
What is a “moving average”

- Low pass filter;
- Central aortic pressure is a low frequency harmonic - Amplification of central-to-brachial systolic pressure is a high frequency harmonic;
- A moving average filters the high frequency harmonic to reveal the central aortic systolic pressure;
- Denominator for the filter is critical \( = \frac{1}{4} \times \text{sampling } f \) of the tonometer.
N-point Moving Average to Derive CASP from the RAPWF

Williams B, et al. in press 2010
Comparison and Concordance of methods to derive CASP from the RAPWF

Williams B, et al. in press 2010
Comparison of NpMA-derived CASP, non-invasively derived from the radial artery, versus invasive aortic root pressure

\[ y = 0.9572x + 5.5555 \]
\[ R^2 = 0.9835 \]
\[ r = 0.9917 \]

\( N = 20 \)

Williams B, et al. in press 2010
Example of available devices and methods for deriving central aortic pressures

**SphygmoCor**
- GTF
- Static measurements

**Omron HEM 9000AI**
- SBP2
- Static measurements

**Bpro**
- Moving Average
- Static and Ambulatory measurements
Comparisons of non-invasive brachial versus invasive aortic pressures

Non-invasive Central Aortic Systolic Pressure is the only measure that accurately reflects aortic root pressure!
Relationship between Brachial and Central Aortic Pressures
Relationship between Brachial and Central Aortic Systolic BP

Variation in Central Aortic Systolic Pressure (CASP) versus Brachial Systolic in normotensive people

N = 2280 (1087 females and 1193 males)

$y = 0.12x - 4.73$

$R^2 = 0.11$

*Williams B, CM Ting, et al. 2010*
Difference between brachial systolic pressure and CASP: Variance according to age

N = 2280 (1087 females and 1193 males)

Williams B, CM Ting, et al. 2010
Incident Hypertension after 10 years is predicted by central aortic pressure rather than brachial pressure

- These data show that in ISH of the young, the risk of hypertension needing treatment may vary according to the level of central BP.
- ISH subjects with low central BP have normal arterial compliance and are at low risk of hypertension needing treatment.

Mos L, et al. ESC 2010
Central Aortic Pressures and Clinical Outcomes
Central aortic pressure and clinical outcomes
Bryan Williams and Peter S. Lacy

Journal of Hypertension 2009, 27:1123–1125

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Central Aortic Pressures and Major Clinical Outcomes in Recent Clinical Studies

<table>
<thead>
<tr>
<th>Patient group</th>
<th>Follow-up (months)</th>
<th>Outcome</th>
<th>Number of events</th>
<th>Dominant BP variable in multivariate analysis</th>
<th>Hazard ratio per 10 mmHg* or SD (95% CI)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-stage renal disease</td>
<td>52</td>
<td>All cause mortality</td>
<td>70</td>
<td>Central pulse pressure (C)</td>
<td>1.4 (1.1–1.8)</td>
<td>Satar et al. [5]</td>
</tr>
<tr>
<td>Male coronary heart disease patients</td>
<td>39</td>
<td>All cause mortality</td>
<td>64</td>
<td>Central pulse pressure (D)</td>
<td>1.18a (1.05–1.33)</td>
<td>Chirinos et al. [6]</td>
</tr>
<tr>
<td>Treated hypertensive patients</td>
<td>36</td>
<td>Composite of CV events</td>
<td>305</td>
<td>Central pulse pressure (R)</td>
<td>1.11a (1.0–1.21)</td>
<td>Williams et al. [3]</td>
</tr>
<tr>
<td>Unselected cohort of American Indians</td>
<td>58</td>
<td>Fatal and nonfatal CV events</td>
<td>319</td>
<td>Central pulse pressure (R)</td>
<td>1.15a (1.07–1.24)</td>
<td>Roman et al. [7]</td>
</tr>
<tr>
<td>Unselected elderly population</td>
<td>96</td>
<td>CV mortality</td>
<td>45</td>
<td>Central systolic pressure (C)</td>
<td>1.33a (1.03–1.72)</td>
<td>Pini et al. [8]</td>
</tr>
<tr>
<td>Coronary heart disease patients</td>
<td>54</td>
<td>Fatal and nonfatal CV events</td>
<td>246</td>
<td>Central pulse pressure (D)</td>
<td>1.25 (1.09–1.43)</td>
<td>Jankowski et al. [9]</td>
</tr>
<tr>
<td>Unselected Chinese community</td>
<td>120</td>
<td>CV mortality</td>
<td>130</td>
<td>Central systolic pressure (C)</td>
<td>1.30a (1.12–1.52)</td>
<td>Wang et al. [10]</td>
</tr>
</tbody>
</table>

can be quite marked in young healthy people, and a typical brachial:aortic ratio is 1.5. The amplification process diminishes with ageing, principally due to aortic stiffening and an increased pulse wave velocity. Thus, with ageing or aortic stiffening or both, central aortic pressures are closer to the brachial pressures but are rarely the same [2].
Central blood pressure: getting to the heart of the matter
Giuseppe Schillaci and Guido Grassi

Relations of central and brachial blood pressure to left ventricular hypertrophy and geometry: the Strong Heart Study
Mary J. Roman, Peter M. Okin, Jorge R. Kizer, Elisa T. Lee, Barbara V. Howard and Richard B. Devereux

Conclusion Left ventricular hypertrophy is more strongly related to systolic pressure than to pulse pressure. Furthermore central pressures are more strongly related than brachial pressures to concentric left ventricular geometry.

## Importance of Central Aortic Systolic Pressure

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<th>BP</th>
<th>Hazard ratio (95% CI)</th>
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<tr>
<td></td>
<td>Univariate</td>
</tr>
<tr>
<td>Systolic [per SD]</td>
<td>1.17 [1.01 - 1.36]</td>
</tr>
<tr>
<td>Diastolic [per SD]</td>
<td>0.92 [0.79 - 1.07]</td>
</tr>
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"Ascending aortic SBP, but not DBP is independently related to the risk of major CV events in patients undergoing coronary angiography"

P. Jankowski et al, ESC 2010.
Novel Pressure Indices and Cardiovascular Outcomes

**UNIVARIATE ANALYSIS:** Cardiovascular events were closely related to both excess pressure time integral (HR 2.50 [1.51-4.14], p<0.001), excess peak pressure (HR 1.02 [1.00-1.04], p=0.012), and central pulse pressure (HR 1.02 [1.00-1.03], p=0.008).

**MULTIVARIATE ADJUSTMENT:** Only excess pressure time integral remained significant (HR 2.77 [1.64-4.65], p<0.001).

*Davies J, et al. ESC 2010.*
Central Aortic Pressures and Differential Drug Effects
Brachial and Central Aortic Systolic Blood Pressure (± 95% CI)

Brachial SBP
Diff Mean (AUC) = 0.7 (-0.4, 1.7) mm Hg

Central SBP
Diff Mean (AUC) = 4.3 (3.3, 5.4) mm Hg

Atenolol: 133.9, 133.2, 125.5, 121.2
Amlodipine: 133.2, 133.2, 125.5, 121.2

What is a normal Central Aortic Systolic Pressure?
## What is a “normal” Central Aortic Systolic Pressure?

Central Aortic Systolic Pressure normal range (N = 5320)

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<th>Age (years)</th>
<th>(mmHg)</th>
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Taking this new clinical science into routine clinical practice
Measuring Central Aortic Systolic Pressure in routine clinical Practice 2010
Central Aortic Pressure: To the heart of the matter

Conclusions

• Brachial BP remains the current gold standard for BP measurement in clinical trials and clinical practice;
• However, brachial BP an accurate measure or aortic pressure;
• Central aortic pressure may be a better predictor of target organ damage, progression to overt hypertension, and clinical outcomes than brachial pressure;
• Central systolic pressure is a better predictor of outcomes that central diastolic pressure;
• Additional indices derived from the radial pressure wave form (excess pressure integral) may also improve the prediction of cardiovascular risk;
Conclusions

• We need now need to develop and evaluate simple and inexpensive clinical tools to non-invasively measure central aortic pressures;

• We need to use these tools to gain more information about the impact of drug therapies on central aortic pressures – physiological template for drug development;

• We need to use these tools to gather more data on the normal ranges and predictive value of central pressures and pulse wave indices from large scale intervention trials;
Systolic pressure is all that matters

Bryan Williams, Lars H Lindholm, Peter Sever

Blood pressure is usually expressed as two components—diastolic and systolic pressures. Systolic hypertension is much more common than diastolic hypertension, and systolic blood pressure contributes more of the huge global disease burden attributable to hypertension than does diastolic pressure. However, there has undoubtedly been confusion about the relative pressure with age, accompanied by a fall in diastolic pressure and a widening in pulse pressure. Increased pulse pressure is therefore indicative of large artery disease and is also associated with increased cardiovascular risk. However, assessment of systolic pressure is sufficient to capture this component of risk, since there is hardly ever a situation in which pulse

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