Estimation of central aortic pressure by SphygmoCor® requires intra-arterial peripheral pressures

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ABSTRACT

Central arterial pressure, measured close to the heart, may be of more patho-physiological importance than conventional non-invasive cuff blood pressure. The technique of applanation tonometry using SphygmoCor® has been proposed as a non-invasive method of estimating central pressure. This relies on mathematically derived generalized transfer functions, which have been previously validated using invasive peripheral pressure measurements. We compared simultaneous estimates of central aortic pressure using this technique with those measured directly during the routine diagnostic cardiac catheterization of 30 subjects (age range 27–84 years), half of whom were aged 65 years or more. This was done by applanating the left radial artery and recording the non-invasive brachial cuff blood pressure to generate a central aortic pressure estimate, using the SphygmoCor® radial transfer function. The comparative results were analysed using Bland–Altman plots of mean difference. SphygmoCor®, on average, underestimated systolic central arterial pressure by 13.3 mmHg and overestimated diastolic pressure by 11.5 mmHg. The results were similar in patients aged under and above 65 years. Furthermore, non-invasively measured brachial pressures were seen to give an overall closer estimate of the central arterial pressure than the SphygmoCor® system. The transfer function has been validated from invasively measured arterial pressures and the current use by the system of non-invasive measures may explain the discrepancies. However, age, drugs and arterial disease would also be expected to play a role.

INTRODUCTION

Non-invasive sphygmomanometric estimates of peripheral brachial blood pressure (BP) have been routinely measured in clinical practice for over one hundred years and accepted as important predictors of cardiovascular morbidity and mortality. At the same time, it has been understood that the central BP, measured close to the heart, is lower than the peripheral pressure due to amplification in the peripheral arteries. This central BP may well be of more patho-physiological significance than the currently measured brachial pressure, although its clinical relevance is not yet proven [1].

There has subsequently been an interest in providing a reliable way of measuring central arterial pressures non-invasively. One such technique uses applanation tonometry (SphygmoCor®, AtCor Medical, West Ryde, NSW, Australia). This involves estimating the central aortic pressure wave from radial artery tonometry using a previously validated mathematical generalized transfer function and a non-invasively measured brachial BP.

Key words: applanation tonometry, catheter central pressure, central aortic pressure, generalized transfer function, radial artery.

Abbreviations: BP, blood pressure; CI, confidence interval.

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The transfer function is a calculation of the relationship between pressure waves at different sites and assumes a linearity between the two [2,3]. To date, such transfer functions have only been investigated clinically in small numbers of patients undergoing diagnostic cardiac catheterization with a mean age of 59 years [1,4–6], using differing computational methods.

There have been several reports of concern over the methods being applied in such validation studies [7,8], particularly as such studies have tended to rely on invasive catheter-measured brachial or radial arterial pressure measurements. When Fetics et al. attempted to validate a different transfer function for ascertaining central pressure, they were forced to abandon indirect measures of brachial pressure for invasive measures, due to large variations between upper arm cuff oscillometric pressure and simultaneously measured invasive pressures in more than half the subjects measured [9]. Furthermore, when non-invasive calibration was attempted and the results published [10], the transfer function gave an estimated central aortic systolic pressure 11 mmHg lower than that measured invasively and a diastolic pressure 8 mmHg higher.

The AtCor Medical device (SphygmoCor®) has been previously shown to have acceptable inter-observer reproducibility [11–13]. However, it remains to be confirmed that the central pressures estimated non-invasively are close to the actual measurements, especially in older subjects where more variation between invasive and non-invasive brachial arterial pressure measurements would be expected.

This study was designed to compare SphygmoCor®-derived measurements of central aortic BP with those simultaneously obtained at routine diagnostic left heart catheterization in subjects aged 65 years or more and subjects of less than 65 years old.

**METHODS**

**Subjects**

We estimated the central aortic BP using SphygmoCor® in 30 subjects undergoing routine day case diagnostic left heart catheterization, half of whom were aged 65 years or more. The indication for cardiac catheterization in all cases was ‘risk stratification’ for anginal symptoms to determine the extent, if any, of coronary vascular disease. Informed consent for additional non-invasive BP measurements being taken during the procedure was gained in each case. The study had approval from the Local Ethics Committee. Atrial fibrillation was the only exclusion criterion.

**BP measurements**

Non-invasive brachial BP was measured using an Omron automatic oscillometric digital BP monitor (HEM-70 CP) in the left arm of the subject in the supine position. The BP was recorded immediately prior to every tonometric recording.

**Applanation tonometry**

Applanation tonometry was performed on the left radial artery, throughout the initial part of the cardiac catheterization and up until the point when central aortic pressure readings were being taken. This was done by lightly applying a micromanometer-tipped probe to the left radial artery over the extended wrist, compressing the vessel wall sufficiently so that transmural forces within the vessel wall were perpendicular to the arterial surface. All readings recorded were seen to meet the manufacturer’s quality control standards integrated into the software package.

**Cardiac catheterization**

Cardiac catheterization was performed in each subject, under local anaesthesia with 1 % lignocaine, via right femoral artery puncture using a cordis 6F pigtail catheter. No other sedation or anaesthetic agents were used. Central aortic pressures were recorded over 10 s using Marquette Midas® system 4000.

**Statistical analysis**

Bland–Altman plots were used to compare predicted central aortic pressures given by the SphygmoCor® system with those measured invasively at cardiac catheterization. This analysis plots the difference between the two readings against the average of the two readings, and has now been widely accepted as a good way of comparing two comparative measurements in medicine [14]. Comparisons of the two age groups of under and above 65 years were made by unpaired t tests and χ² tests as appropriate. The 95 % confidence intervals (CIs) are presented.

**RESULTS**

Thirty subjects were studied, with a mean age of 53.5 years in the under 65 years group (n = 15) and a mean age of 73.9 years in the over 65 years group (n = 15). The mean age for the entire sample was 63.7 years (range 27–84 years). Patient characteristics are shown in Table 1. The recordings used for the final analysis were taken to be the measurements nearest in time to the recording of the catheter central aortic pressure and the mean differences were very similar to that found in an analysis performed on mean data of all readings recorded during the catheter procedure. Results showing the mean differences between estimated pressures and those measured invasively are shown in Table 2.

For the group as a whole, SphygmoCor® underestimated catheter-measured central aortic pressure by
Table 1  Patient characteristics
This table shows the baseline characteristics of all the patients studied. *P value when comparing < 65 years age group with the > 65 years group.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>All cases (n = 30)</th>
<th>Age &lt; 65 years (n = 15)</th>
<th>Age &gt; 65 years (n = 15)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>63.7 ± 13.3</td>
<td>53.5 ± 10.1</td>
<td>73.9 ± 6.3</td>
<td>0.47</td>
</tr>
<tr>
<td>Number of males</td>
<td>18 (60 %)</td>
<td>9 (60 %)</td>
<td>9 (60 %)</td>
<td></td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.9 ± 4.4</td>
<td>27.5 ± 5.2</td>
<td>26.3 ± 3.6</td>
<td>0.46</td>
</tr>
<tr>
<td>Smoking</td>
<td>17 (57 %)</td>
<td>10 (67 %)</td>
<td>7 (47 %)</td>
<td>0.46</td>
</tr>
<tr>
<td>Coronary disease</td>
<td>17 (57 %)</td>
<td>7 (47 %)</td>
<td>10 (67 %)</td>
<td>0.46</td>
</tr>
<tr>
<td>Hypertension</td>
<td>15 (50 %)</td>
<td>7 (47 %)</td>
<td>8 (53 %)</td>
<td>0.04</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>8 (27 %)</td>
<td>1 (7 %)</td>
<td>7 (47 %)</td>
<td></td>
</tr>
<tr>
<td>Mean brachial systolic BP (mmHg)</td>
<td>154.9 (27.1)</td>
<td>144.7 (26.1)</td>
<td>165.1 (24.8)</td>
<td>0.03</td>
</tr>
<tr>
<td>Mean SphygmoCor® systolic BP (mmHg)</td>
<td>143.5 (27.8)</td>
<td>133.9 (27.1)</td>
<td>153 (25.9)</td>
<td>0.62</td>
</tr>
<tr>
<td>Mean catheter systolic BP (mmHg)</td>
<td>156.8 (32.1)</td>
<td>145.8 (28.9)</td>
<td>167.7 (32.4)</td>
<td>0.06</td>
</tr>
<tr>
<td>Mean catheter diastolic BP (mmHg)</td>
<td>77.9 (12.9)</td>
<td>78.9 (9.6)</td>
<td>76.9 (15.8)</td>
<td>0.70</td>
</tr>
<tr>
<td>Brachial pulse pressure (mmHg)</td>
<td>66.5 (18.6)</td>
<td>58.2 (15.4)</td>
<td>74.8 (18.3)</td>
<td>0.01</td>
</tr>
<tr>
<td>SphygmoCor® pulse pressure (mmHg)</td>
<td>54.1 (18.2)</td>
<td>46.5 (15.1)</td>
<td>61.7 (18.3)</td>
<td>0.02</td>
</tr>
<tr>
<td>Catheter pulse pressure (mmHg)</td>
<td>78.9 (26.7)</td>
<td>66.9 (21.9)</td>
<td>90.9 (26.1)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 2  Mean differences between estimated central pressures by SphygmoCor® and those measured invasively
This table shows the mean difference between the estimated central pressures by SphygmoCor® and cuff brachial sphygmonanometry and those measured invasively by cardiac catheterization. MP, mean arterial pressure. *P value as in Table 1.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>All cases (S.D.) [upper/lower 95 % CI]</th>
<th>Age &lt; 65 years (S.D.) [upper/lower 95 % CI]</th>
<th>Age &gt; 65 years (S.D.) [upper/lower 95 % CI]</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central systolic catheter pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachial</td>
<td>1.9 (15.8) [− 4/7.8]</td>
<td>1.1 (17.0) [− 0.2/10.5]</td>
<td>2.7 (15.1) [− 5.7/11]</td>
<td>0.79</td>
</tr>
<tr>
<td>SphygmoCor®</td>
<td>13.3 (15.1) [7.7/18.9]</td>
<td>11.9 (15.9) [3.1/20.7]</td>
<td>14.7 (14.7) [6.5/22.8]</td>
<td>0.62</td>
</tr>
<tr>
<td>Central diastolic catheter pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachial</td>
<td>− 10.5 (9.7) [− 14/− 6.8]</td>
<td>− 7.5 (8.6) [− 12/− 2.8]</td>
<td>− 13.4 (10.1) [− 19/− 7.8]</td>
<td>0.10</td>
</tr>
<tr>
<td>SphygmoCor®</td>
<td>− 11.5 (9.8) [− 15/− 7.8]</td>
<td>− 8.5 (8.7) [− 12/− 3.6]</td>
<td>− 14.5 (10.1) [− 20/− 8.9]</td>
<td>0.09</td>
</tr>
<tr>
<td>Central MP catheter (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachial</td>
<td>− 1.8 (9.5) [− 5.5/1.8]</td>
<td>0.9 (9.7) [− 4.5/6.3]</td>
<td>− 4.5 (8.9) [− 9.4/0.4]</td>
<td>0.12</td>
</tr>
<tr>
<td>SphygmoCor®</td>
<td>− 1.8 (9.5) [− 5.5/1.8]</td>
<td>0.9 (9.7) [− 4.5/6.3]</td>
<td>− 4.5 (8.9) [− 9.4/0.4]</td>
<td>0.12</td>
</tr>
</tbody>
</table>

In terms of diastolic pressure, estimates tended to be more extreme in the older age group. Non-invasive brachial pressure overestimated diastolic catheter-measured central pressure by 13.4 mmHg in subjects over 65 years compared with 7.5 mmHg in those under 65 years (P = 0.1 for the difference), while SphygmoCor® similarly overestimated pressure by 14.5 mmHg in the over 65 years subjects compared with 8.5 mmHg in the younger patients, with a mean difference of 11.5 mmHg for both groups combined (P < 0.1 for

an average of 13.3 mmHg (95 % CI 7.7/18.9) and overestimated diastolic and mean arterial pressure by 11.5 (95 % CI 15/− 7.8) and 1.8 mmHg (95 % CI −5.4/1.8) respectively.

In subjects under 65 years, on average brachial pressure provided a close approximation to catheter-measured central systolic pressure, whereas SphygmoCor® underestimated the central systolic pressure by 11.9 mmHg. This difference tended to be greater in those subjects over 65 years, where non-invasive brachial pressure underestimated the central systolic pressure by 2.7 mmHg and SphygmoCor® by 14.7 mmHg (although this difference between the two groups was not significant with P > 0.1 for the difference). Mean differences for all subjects studied showed that SphygmoCor® underestimated central systolic pressure by 13.3 mmHg (Figure 1) and non-invasive brachial pressure underestimated the same pressure by only 1.9 mmHg (Figure 2).
The difference between the two readings is plotted against the average of the two readings. The mean difference is indicated with the 2 S.D. limits. •, Age under 65 years; ○, age over 65 years.

The +2 S.D. range was approx. 60 mmHg for systolic pressure and 40 mmHg for diastolic pressure.

Pulse pressure (calculated as the difference between systolic and diastolic pressure) was greatest, as expected, in the older group. The central pulse pressure estimated...
by SphygmoCor® was 24.8 mmHg less than that measured by catheter for all subjects and 29.2 mmHg for the older group (Table 2).

**DISCUSSION**

Non-invasive BP measurements to produce SphygmoCor® estimates of central aortic pressure did not agree well with the central pressure as measured by cardiac catheter.

These results are of a similar magnitude of error as found in the previous study performed by Takazawa et al. [10], using non-invasive BP to calculate a central aortic pressure with the generalized transfer function. They found an underestimate of systolic central aortic pressure by 11 mmHg and an overestimate of diastolic central aortic pressure by 8 mmHg compared with our present readings in the <65 years group of 11.9 mmHg and 8.5 mmHg respectively. This undermines the use of a generalized transfer function using non-invasive brachial BP recordings. The discrepancy between machine estimate and actual measure is best explained by the inherent differences between cuff and invasively measured brachial or radial pressure.

Taken at ‘face-value’, these results suggest that using SphygmoCor® to estimate central aortic pressure is no more accurate than assuming non-invasive brachial BP to be an equivalent pressure. This problem was the same in both age groups.

It has been known for more than fifty years that there are considerable differences between cuff measurements of brachial pressure and invasive measures, especially in older subjects [15–20]. Finnegan et al. [17] in one such study involving a volunteer group of 57 subjects (mean age 68.6 years) found that on average cuff pressure significantly underestimated systolic pressure by 5 mmHg compared with catheter measurements, while diastolic brachial cuff pressure was 8 mmHg higher. Estimates of mean arterial pressure differed far less, but there were wide variations with cuff pressure underestimating systolic BP by more than 10 mmHg in one third of cases. It is perhaps not surprising that using cuff pressure measurements with a generalized transfer function, which has been validated using invasive techniques [17], does not seem to accurately estimate central pressure. In this context it is worth noting that the Omron (HEM-705 CP) has been fully validated against the mercury sphygmomanometer [21].

The subjects analysed in this study were also heterogeneous for age, drugs and arterial disease (unlike a cohort of healthy volunteers). Age, drugs and disease can all affect the vascular properties of an artery [22–25]. It is therefore unclear as to whether using a standard mathematical generalized transfer function for all individuals, regardless of age or extent of concomitant
vascular disease, will reliably predict the central aortic pressure on extrapolation.

This study does have limitations besides the small numbers of subjects measured. Due to the nature of recording cardiac catheter data, the time taken to record a non-invasive BP and then apply the radial artery and the dynamic nature of BP, the time-point interval between predicted and measured readings was not constant and the two were not truly simultaneous. However, analysing mean data of all readings taken prior to catheter measurement of central aortic pressure and comparing them with the readings taken nearest in time to the catheter measurement showed very similar results, suggesting that this was not an explanation for the results.

Another issue to be addressed is the use of a fluid-filled catheter to assess central systolic pressure. These catheters are under-damped and have slow response times. Nevertheless, although they may not be sufficiently accurate to measure rate of pressure change (dP/dt) [26], the duration of peak central systolic pressure is such that the fluid-filled catheter should achieve a stable equilibrated value. Catheter tip micromanometers are no longer in routine use in our laboratory because of their cost, baseline instability and the necessity for calibration against a mercury sphygmomanometer. We therefore consider that our results would be replicated by a carefully calibrated catheter tip micromanometer system.

Finally, only the left radial artery was used forplanation in this study, and it may well be that the carotid artery transfer function works better, although in a clinical setting the radial is by far the most convenient artery to examine from both the patient’s and clinicians’ point of view, and is the one method recommended by the manufacturers.

In conclusion, our study provides evidence against the use of non-invasive measurements of brachial pressure with the SphygmoCor® generalized transfer function to estimate central aortic pressure.

ACKNOWLEDGMENTS

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