The importance of calibration method in determining the association between central blood pressure with left ventricular and left atrial strain

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Abstract
Afterload is an important determinant of left ventricular (LV) and atrial (LA) function, including myocardial strain. Central blood pressure (CBP) is the major component of cardiac afterload and independently associated with cardiovascular risk. However, the optimal means of calibrating CBP is unclear—standard CBP assessment uses systolic (SBP) and diastolic blood pressure (DBP) from brachial waveforms, but calibration with mean pressure (MAP) and DBP purports to be more accurate. Therefore, we sought to determine which CBP is best associated with LA and LV strain. CBP was measured using both standard and MAP based calibration methods in 546 participants (age 70.7 ± 4.7 years, 45% male) with risk factors for heart failure. Echocardiography was performed in all patients and strain analysis conducted to assess LA/LV function. The associations of CBP with LA and LV strain were assessed using linear regression. MAP-derived CSBP (150 ± 20 mmHg) was higher than standard CSBP (128 ± 15 mmHg) and brachial SBP (140 ± 17 mmHg, p < 0.001), whereas DBPs were similar (84 ± 10, 83 ± 10, and 82 ± 10 mmHg). MAP-derived CSBP was not independently associated with LV strain (p > 0.05), however was independently associated with LA reservoir strain (p < 0.05). Brachial and central DBP were more strongly associated with LA reservoir/conduit and LV strain than brachial and central SBP. LA pump strain was not independently associated with any SBP or DBP parameter (p > 0.05). MAP-derived CBP was more accurate in identifying patients with abnormal LA and LV strain than brachial SBP and standard CBP calibration. In conclusion, CBP calibrated using MAP and DBP may be more accurate in identifying patients with abnormal LA and LV function than standard brachial calibration methods.

Keywords Strain · Left atrium · Atrial function · Central blood pressure

Abbreviations
ACE-I Angiotensin converting enzyme inhibitors
AF Atrial fibrillation
BMI Body Mass Index
BP Blood pressure
CBP Central blood pressure
DBP Diastolic blood pressure
ECG Electrocardiograph
GLS Global longitudinal strain
HF Heart failure
LA Left atrium
LV Left ventricle
LVEF Left ventricular ejection fraction
LVH Left ventricular hypertrophy
LVM Left ventricular mass
MAP Mean arterial pressure
SBP Systolic blood pressure
T2DM Type II diabetes mellitus
Tas-ELF Tasmanian AF screening cohort
TTE Transthoracic echocardiography

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Hypertension is a leading cause of morbidity and mortality [1, 2]. Recent changes in clinical practice guidelines have advocated for an aggressive approach in the diagnosis and treatment of hypertension [1]. However, there remains contention regarding the use of the most appropriate blood pressure (BP) marker [3], which is easily measurable, reproducible, and correlates with clinical outcomes. Some studies demonstrated that central blood pressure (CBP) is more closely associated with cardiovascular outcomes compared with peripheral brachial BP [4–7], although some did not [8]. There are multiple non-invasive methods of estimating central (aortic) pressure [9]. Most commonly, a waveform calibration method is to use brachial systolic blood pressure (SBP) and diastolic blood pressure (DBP). This method may be associated with inaccuracy leading to underestimation of the systolic CBP and overestimation of diastolic CBP [10]. The use of mean arterial pressure (MAP) along with DBP may be a more accurate calibration method of CBP [9]. We previously reported better associations between MAP-derived CBP and cardiac anatomy as a marker of end-organ damage [11] but little is known about relationships with cardiac function. Identifying the BP parameter most closely associated with altered cardiac function is important because it may indicate those with early signs of end-organ damage related to hypertension.

Strain analysis using speckle tracking allows for quantitative assessment of left atrial (LA) and left ventricular (LV) function. Hypertension has a direct impact on both LV and LA function—the latter through LV stiffness contributing to increased LA pressure leading to LA dilatation and fibrosis [12]. In this study, we aimed to elucidate the associations between the BPs and myocardial deformation parameters with the strongest correlation with target organ functional alteration.

Methods

Study population

This is a cross-sectional study using baseline data from a large community-based study of stage A heart failure (HF), with the primary objective of early detection of left ventricular dysfunction using strain imaging (Tas-ELF study, ACTRN12614000080628). Asymptomatic participants ≥ 65 years were recruited if they had 1 or more risk factors, including hypertension (SBP ≥ 140 mmHg, DBP ≥ 90 mmHg or pre-existing use of anti-hypertensive medications), type 2 diabetes mellitus (T2DM, based on self-report of diagnosis or the current use of diabetic medications), or obesity (defined as a body mass index ≥ 30 kg/m²). Exclusion criteria included: (1) inability to provide written consent to participate in the study, (2) history of moderate or greater valvular disease, (3) known history of HF, (4) reduced LV systolic function on baseline echocardiography (LVEF < 40%), (5) contraindications to beta blockers or angiotensin converting enzyme inhibitors (ACE-I), (6) expected life expectancy of less than 1 year or (7) inability to perform strain analysis or acquire interpretable images from baseline echocardiogram. All patients with a known history of AF or documented AF on the baseline ECG were excluded from the study. All patients were provided written informed consent and approval was obtained from the institution’s Human Research Ethics Committee (University of Tasmania HREC project number H0013333).

Baseline data collection

All participants undertook a clinical history and answered questionnaires to assess overall health status at the start of the study. Information regarding demographics, past medical history, medication history as well as baseline examination data (height, weight, body mass index (BMI)) was recorded for all participants. Baseline electrocardiography (ECG) and echocardiography was conducted in all participants.

Blood pressure measurement

Peripheral BP (3 × measurements) was measured in the supine position following a minimum of 10 min in a quiet room without auditory stimuli. A validated oscillometric device (Mobil-O-Graph, IEM, Stolberg, Germany) was used for all measurements. CBP was measured using two calibration methods. Standard CBP was measured from calibration of the brachial BP waveforms using oscillometric SBP and DBP. Using an automated batch method, each brachial BP waveform was then recalibrated to derive MAP based CBP using oscillometric MAP and DBP measurements. Cut-offs for hypertension using CBP and brachial BP was determined as BP ≥ 140/80 mmHg. Figure 1 shows the various components of BP measurement.

Echocardiography

All echocardiograms were performed by qualified sonographers who were blinded to clinical information using the same equipment (Siemens ACUSON SC2000, Siemens Healthcare, Mountain View, CA) and transducers (4V1c, 1.25–4.5 MHz; 4Z1c, 1.5–3.5 MHz). Two-dimensional, M-mode, and Doppler measures were obtained using standard techniques outlined by the American Society of Echocardiography. LV dimensions were calculated in both diastole and systole in parasternal long axis views. LV hypertrophy (LVH) was defined as LVM index > 115 g/m² in men and > 95 g/m² in women. LV and LA volumes were indexed...
to body surface area (LAVi) and calculated by the biplane method of discs. Abnormal LAVi was defined as ≥ 34 ml/m².

Global longitudinal strain (GLS) was calculated in apical views using speckle tracking imaging. Manual tracing of the endocardial border of the LV was performed in end-systole and this was tracked during the cardiac cycle. Abnormal GLS was defined as > − 16% [13]. LA reservoir, conduit and pump strain were assessed using speckle tracking imaging by an external third-party software program (ImageArena, Tomtec, Munich, Germany). Apical four and two chamber images were selected with a frame rate of 60–80 frames/sec. The endocardial border of the LA was manually traced and strain analysis was performed using the LV strain algorithm, utilizing the average of both the four- and two-chamber values. The reference point for image analysis was taken at the onset of the QRS complex (R-R gating). An example of the LA strain curve and measurement in Fig. 2. Abnormal LA strain was defined as LA reservoir strain < 38%, LA conduit < 21% and LA pump strain < 16%. Patients with poor image quality, where strain analysis could not be performed, were excluded. All strain measurements were performed by two investigators. Reproducibility was assessed using a random sample of 20 patients and mean percentage difference was calculated.

**Statistical analysis**

All categorical variables are presented as frequencies/percentages and continuous variables presented as means/standard deviation (if normally distributed) or medians/IQR (if non-parametric). Clinical and echocardiographic characteristics were compared in participants
with normal/abnormal GLS. Baseline characteristics were compared using the chi-square test for categorical data, and Student t-test for continuous data or the Mann–Whitney U test as appropriate. The correlation between standard and MAP-derived CBP was assessed using scatterplots and Pearson’s r. Scatterplots were also used to compare both standard and MAP-derived CBP based on the presence of reduced GLS/LA strain. Multivariable linear regression analysis was used to assess the independent association between BP parameters and strains by adjusting BMI, T2DM, family history of HF, use of angiotensin-converting enzyme inhibitors/angiotensin receptor blockers, beta blockers, calcium channel blockers and diuretics. Correlation co-efficients between standard and MAP-derived CBP were compared using Steiger’s Z test. Analyses were considered statistically significant if 2-tailed p-values were < 0.05. Statistical analysis was performed using SPSS v.22 (SPSS, Chicago, IL), R version 3.5.0 [https://www.r-project.org]) and Stata v.13 (StataCorp, College Station, Texas).

**Results**

**Baseline characteristics**

A summary of baseline patient characteristics is shown in Table 1. A total of 546 patients were included in the study (age 70.7 ± 4.7 years, male 45%). Most patients had T2DM (52%), obesity (43%), hypercholesterolemia (54%) and hypertension (79%). The mean GLS, LA reservoir, conduit, and pump strain of the overall cohort was −18.6 ± 2.5%, 39.3 ± 6.8%, 19.9 ± 5.4%, and 19.4 ± 5.0%, respectively.

87 participants (16%) of the cohort had abnormal GLS (GLS −14.6% ± 1.3% vs. −19.3% ± 1.9% in those with normal GLS, p < 0.001). Those with abnormal GLS had higher BMI, were more likely to have a diagnosis of diabetes mellitus and had reduced exercise capacity based on the six-minute walk test (p < 0.05). SBPs were not significantly different in those with normal and abnormal GLS (p > 0.05), however, those with abnormal GLS had higher DBP compared with those with normal GLS (85.2 ± 10.3 vs. 81.1 ± 10.2 mmHg for brachial DBP, 86.7 ± 10.4 vs. 82.1 ± 9.9 mmHg for standard central DBP and 87.7 ± 10.9 vs. 83.0 ± 10.0 mmHg for MAP-derived central DBP, p ≤ 0.001). LA strains were lower in those with abnormal GLS (36.7% ± 7.9% vs. 39.7% ± 6.5%, p = 0.001 for LA reservoir strain; and 18.1% ± 5.9% vs. 20.2% ± 5.2%, p = 0.002 for LA conduit strain), except for LA pump strain, which was similar among the groups (p > 0.05).

**Correlation between different CBP calibration methods**

Figure 3 illustrates a scatterplot showing the correlation among the three BP methods. MAP-derived central SBP was higher than standard systolic CBP and brachial SBP (150 ± 20 mmHg vs. 128 ± 15 mmHg vs. 140 ± 17 mmHg, both p < 0.001). Whereas MAP-derived central DBP was similar to standard central DBP and brachial DBP (84 ± 10 mmHg vs. 83 ± 10 mmHg vs. 82 ± 10 mmHg, p > 0.05). There was a modest correlation between MAP-derived central SBP and standard central SBP (Pearson’s r = 0.74, p < 0.001). A stronger correlation was observed between standard central SBP with brachial SBP than that between MAP-derived central SBP and brachial SBP (p = 0.018). DBP, MAP-derived central DBP and standard central DBP are very closely correlated to each other (Pearson’s r between 0.93–0.98, all p < 0.001).

**Association between BP and LA/LV strain**

Table 2 summarizes the associations between BPs and strains. DBP (both brachial and central) were independently associated with GLS, LA reservoir, and LA conduit strain (p < 0.05) but not with LA pump strain. Brachial and standard central SBPs were independently associated with GLS (β = −0.09, p = 0.04 for brachial SBP and β = −0.15, p = 0.001 for standard central SBP). MAP-derived central SBP was independently associated with LA reservoir strain (β = −0.12, p = 0.01) but not with GLS or LA conduit strain (p > 0.05). No BP parameter was independently associated with LA pump strain (p > 0.05).

**Discrimination of abnormal LA and LV function**

Figures 4 and 5 demonstrate scatterplots among brachial BP, MAP-derived or standard central SBP with abnormal GLS and LA reservoir strain being color-coded (cut-offs reported in methods section). These plots were divided into 4 subsections based on cutoffs for SBP (140 mmHg for both central and brachial SBP). Table 3 also provides data on the sensitivity and specificity of the 3 measures of systolic BP in identifying patients with abnormal V and LA strain. Based on these cut-off values for central BPs, MAP-derived central SBP identified an additional 32 (37%) patients with abnormal GLS (total n = 87 for abnormal GLS) who were classified as normotensive based on standard central SBP criteria (Fig. 4A). For LA strain, MAP-derived central SBP identified an additional 101 (47%) patients with abnormal LA reservoir strain (total n = 213) (Fig. 4C), 157 (49%) patients with abnormal LA conduit strain (total n = 321) (Fig. 5A); and 63 (48%) patients with abnormal LA pump strain (total n = 130) who were classified as normotensive.
Table 1  Baseline characteristics of the overall cohort and participants grouped by GLS (cut-off − 16%)

| Baseline patient characteristics | Entire cohort (n = 546) | Subjects with normal GLS (≤ − 16%) (n = 459) | Subjects with abnormal GLS (> − 16%) (n = 87) | P value |
|----------------------------------|-------------------------|---------------------------------------------|---------------------------------------------|---------|
| Demographics                     |                         |                                             |                                             |         |
| Age (years) (SD)                 | 70.7 (4.7)              | 70.6 (4.7)                                 | 71.3 (4.6)                                 | 0.20    |
| Male n (%)                       | 247 (45)                | 194 (42)                                   | 53 (61)                                    | 0.001   |
| BMI (kg/m²) (SD)                 | 29.4 (5.2)              | 29.2 (5.1)                                 | 30.5 (6.1)                                 | 0.03    |
| Current smoking n (%)            | 12 (2)                  | 11 (2)                                     | 1 (1)                                      | 0.47    |
| Diabetes mellitus n (%)          | 284 (52)                | 224 (49)                                   | 60 (69)                                    | 0.001   |
| Obesity n (%)                    | 234 (43)                | 192 (42)                                   | 42 (48)                                    | 0.27    |
| Hypercholesterolemia n (%)       | 281/533 (54)            | 234/442 (53)                               | 47/80 (59)                                 | 0.34    |
| Hypertension n (%)               | 429 (79)                | 360 (78)                                   | 69 (79)                                    | 0.86    |
| Previous history of IHD n (%)    | 38 (7)                  | 29 (6)                                     | 9 (10)                                     | 0.18    |
| Median six minute walk test m(IQR)| 485 (115.5)             | 490 (111.8)                                | 469 (129.0)                                | 0.02    |
| Medications                      |                         |                                             |                                             |         |
| Beta blockers n (%)              | 34 (6)                  | 24 (5)                                     | 10 (12)                                    | 0.03    |
| ACE inhibitor/angiotensin receptor blocker n (%) | 363 (67) | 309 (67) | 54 (62) | 0.34 |
| Calcium channel blocker n (%)    | 117/503 (23)            | 91/425 (21)                                | 26/78 (33)                                 | 0.02    |
| Lipid lowering agents n (%)      | 278/505 (55)            | 231/427 (54)                               | 47/78 (60)                                 | 0.32    |
| Anti-platelet agents n (%)       | 189/502 (38)            | 159/426 (37)                               | 30/76 (40)                                 | 0.72    |
| Blood pressure                   |                         |                                             |                                             |         |
| Brachial systolic BP mmHg (SD)   | 140.0 (16.6)            | 139.7 (15.7)                               | 141.8 (20.6)                               | 0.38    |
| Brachial diastolic BP mmHg (SD)  | 81.7 (10.3)             | 81.1 (10.2)                                | 85.2 (10.3)                                | 0.001   |
| Standard systolic central BP mmHg (SD) | 128.2 (15.2) | 127.9 (14.6) | 130.0 (18.0) | 0.30 |
| Standard diastolic central BP mmHg (SD) | 82.8 (10.2) | 82.1 (9.9) | 86.7 (10.4) | <0.001 |
| MAP derived systolic central BP mmHg (SD) | 150.3 (20.2) | 150.0 (18.7) | 151.7 (26.5) | 0.59 |
| MAP derived diastolic central BP mmHg (SD) | 83.7 (10.3) | 83.0 (10.0) | 87.7 (10.9) | <0.001 |
| Echocardiographic parameters     | Mean (SD)               |                                             |                                             |         |
| Ejection fraction % (SD)         | 63.7 (5.9)              | 64.4 (5.2)                                 | 60.0 (7.6)                                 | <0.001  |
| Global longitudinal strain % (SD) | – 18.6 (2.5)           | – 19.3 (1.9)                               | – 14.6 (1.3)                               | <0.001  |
| E/e’ (average of lateral and septal) (SD) | 8.9 (2.6) | 8.9 (2.6) | 8.8 (2.8) | 0.66 |
| Left atrial volume—indexed ml/m² (SD) | 31.6 (9.2) | 31.5 (9.1) | 32.4 (9.9) | 0.38 |
| LV mass index g/m² (SD)          | 91.5 (22.7)             | 90.0 (21.6)                                | 99.2 (26.8)                                | 0.003   |
| LA reservoir strain % (SD)       | 39.3 (6.8)              | 39.7 (6.5)                                 | 36.7 (7.9)                                 | 0.001   |
| LA conduit strain % (SD)         | 19.9 (5.4)              | 20.2 (5.2)                                 | 18.1 (5.9)                                 | 0.002   |
| LA pump strain % (SD)            | 19.4 (5.0)              | 19.5 (4.9)                                 | 18.6 (5.5)                                 | 0.14    |

based on standard central SBP (Fig. 5C). On the contrary, standard central SBP identified no additional patients with abnormal GLS and only 2 additional patients with abnormal LA strain (1 LA reservoir and 1 LA conduit) who were classified as normotensive based on MAP-derived central SBP. Collectively, net increments of patients with abnormal GLS, LA reservoir, conduit, and pump strain were 32 (37%), 100 (47%), 156 (49%), and 63 (48%), respectively. However, despite increased sensitivity, there was more false positives with MAP-derived central SBP when compared to standard central SBP (see Table 3).

Compared with brachial SBP, MAP-derived central SBP identified an additional 16 (18%) patients with abnormal GLS (Fig. 4B), 36 (17%) patients with abnormal LA reservoir strain (Fig. 4D), 57 (18%) patients with abnormal LA conduit strain (Fig. 5B), and 31 (24%) patients with abnormal LA pump strain who were classified as normotensive based on MAP-derived central SBP criteria. On the contrary, brachial SBP identified an additional 6 patients with abnormal GLS and 17 patients with abnormal LA strain (4 patients with LA reservoir/10 patients with LA conduit and 3 patients with LA pump strain) who were classified as normotensive based on MAP-derived central SBP. Collectively, net increments of patients with abnormal GLS, LA reservoir, conduit, and pump strain were 10 (11%), 32 (15%), 47 (15%), and 28 (22%), respectively. However,
despite increased sensitivity, there was more false positives with MAP-derived central SBP when compared to branchial SBP (see Table 3).

### Reproducibility

Reproducibility was assessed by blinded strain measurements in a random sample of 20 patients. All measurements were done by the same two investigators (SR and TN) and the mean of the absolute value of differences between measurements was calculated. Bland–Altman plots for inter-observer variability is shown in Fig. 6. For GLS the mean ± SD difference was 0.7 ± 0.7%. For LA strain the mean difference was 8.0 ± 7.0% for reservoir strain, 5.3 ± 4.1% for conduit strain and 5.6 ± 4.6% for pump strain. Intra-observer variability was assessed by one investigator (SR) who repeated LA strain measurements in the same 20 patients at a different timepoint. The mean difference for
LA strain was 3.8 ± 2.9% for reservoir strain, 2.7 ± 1.4% for conduit strain and 2.7 ± 1.4% for pump strain.

Discussion

This study demonstrated that MAP-derived central SBP identified more patients with abnormal LA and LV strain (i.e. those with subclinical LV/LA dysfunction) compared with standard central SBP. Strong correlations among DBP (both brachial and central) measurements were observed whilst only moderate correlations in SBP measurements were observed. MAP-derived central SBP was higher than standard central SBP. CBP calibrated using MAP and DBP was more closely associated with LA reservoir strain compared with standard CBP, which is based on SBP and DBP. Compared with SBP, DBP was more strongly associated with LA reservoir/conduit strain and GLS.

Clinical relevance of CBP

Clinical assessment of BP is an essential component of patient assessment. Use of peripheral (brachial) BP is convenient, easily reproducible and non-invasive. Clinical practice guidelines and cardiovascular risk assessment currently depend on brachial BP recordings [1]. However brachial BP only provides a rough estimate of central (aortic) pressure [9]. Previously CBP was only able to be measured invasively,
having a limited clinical role. Newer methods of measuring CBP non-invasively using waveform analysis have several advantages. As noninvasive CBP may be more closely representative of invasive aortic pressure than brachial BP [9, 10, 14], it may have a useful role in assessment of cardiovascular outcomes [4–7], having a prognostic role [7] and potentially associated with improved hypertension management [15]. Measurement of CBP using oscillometric MAP and DBP

Table 3 Sensitivity and specificity for brachial and CBP in identifying patients with abnormal LV and LA strain

|                     | Abnormal GLS (≥ 16%) | Abnormal LA reservoir strain (< 38%) | Abnormal LA conduit strain (< 21%) | Abnormal LA pump strain (< 16%) |
|---------------------|-----------------------|--------------------------------------|------------------------------------|----------------------------------|
|                     | Sens (%) Spec (%)     | Sens (%) Spec (%)                    | Sens (%) Spec (%)                  | Sens (%) Spec (%)               |
| Brachial SBP        | 43 52                 | 49 55                                | 49 55                              | 46 52                           |
| Standard CSBP       | 21 83                 | 20 85                                | 18 84                              | 21 84                           |
| MAP derived CSBP    | 59 31                 | 68 33                                | 67 32                              | 69 33                           |
calibration is a newer method and may be a more accurate method of estimating CBP. It has previously been shown to be closer to the true systolic CBP and may be more strongly associated with clinical outcomes such as left ventricular hypertrophy [11, 16–18]. CBP estimated using brachial SBP and DBP may lead to underestimation of systolic SBP and pulse pressure [11, 18].

**Association of BP with LA/LV strain**

Strain analysis using speckle tracking provides quantitative information of LA and LV function. BP has a strong impact on LA and LV function. Elevated BP leads to LV hypertrophy, reduced compliance and increased stiffness. The increase in LA pressure contributes to LA dilatation and may lead to fibrosis [12, 19]. There is interdependence on the three components of LA strain. LV function has a direct influence on LA reservoir and conduit function [20], where LA pump function has much less association with LV function [20]. This is important in the pathogenesis in conditions such as HF with preserved ejection fraction as well as AF.

In our study, DBPs were more strongly associated with GLS and LA strain than SBPs. This is an interesting finding because SBP is also more commonly used in clinical practice to guide diagnosis. In addition, previous studies have not demonstrated a stronger association between DBP and cardiovascular outcomes compared with SBP [1, 21]. Our finding may have important clinical implications and highlights the potential importance in monitoring DBP in patients with hypertension and the use of DBP in identifying those with subclinical
LA/LV dysfunction. Very strong mutual correlations were noted among all three methods of DBP, with little difference in measured values. Thus, there may not be additional utility in measurement of central DBP compared with brachial DBP or standard central DBP.

Furthermore, we observed that mean MAP-derived central SBP was higher than brachial SBP and standard central SBP. A weaker correlation between MAP-derived central SBP and brachial SBP compared with standard central SBP, suggesting MAP-derived central SBP may possess different diagnostic signals to brachial BP. Indeed, MAP-derived central SBP identified more patients with abnormal LV and LA strain than standard central SBP/brachial SBP did. These observations have important clinical implications. Noninvasive BP are different among calibration methods. MAP-derived CBP may help identify those with end organ functional alteration earlier, where subclinical LV and LA dysfunction are risk factors for developing overt HF or atrial fibrillation (AF) [22–24]. Therefore, MAP-derived central SBP may be utilized as a gate keeper to rule-out low risk patients and identify those who would benefit from further advanced echocardiographic assessment. This finding is also consistent with our previous findings showing that MAP-derived central SBP had increased discriminatory power compared with other SBP markers in detecting those with LVH and LA enlargement in patients with stage A HF [11]. The increased sensitivity noted with MAP-derived central SBP has a trade off with reduced specificity. Standard central SBP consistently demonstrated the best specificity for both LV and LA strain. However, with most screening tests where we aim to rule out disease, a more sensitive BP parameter would be more useful.

Use of CBP in hypertension management

CBP may be a more appropriate BP marker to use in the diagnosis of hypertension. MAP-derived central SBP was noted in our study to be higher than brachial SBP and standard central SBP, which has been observed in other studies [11, 18]. This suggests an underestimate of central SBP using brachial SBP calibration. Given recent guidelines have advocated for earlier recognition of patients with hypertension and more aggressive treatment of BP [1], the use of a more sensitive marker will aid diagnosis and monitoring. As anti-hypertensive drugs have different effects on CBP than peripheral BP, the use of CBP may result in improved drug titration and may represent a more accurate reflection on treatment response [7, 9, 25–28].

Comparison of MAP-derived and standard CBP calibration methods

There are multiple different calibration methods used to calculate CBP non-invasively [9]. Previously there were no standardized guidelines and different algorithms, and calibrations were utilized leading to discrepancy in the accuracy of CBP measurements. A recent taskforce has been established to help create more uniform standards [9]. The use of different calibration standards has potentially a large impact on clinical outcomes. We noted a large discrepancy in SBP recordings using the two most common CBP calibration methods and brachial BP. DBPs were much more strongly correlated with each other. Future research is required in determining the most appropriate calibration method which should be used in measuring CBP. Currently brachial BP offers a simple, effective and reproducible assessment of BP in clinical practice. However, with further improvements in determining CBP accurately using non-invasive, cost effective methods, may translate into a more feasible assessment tool for clinical practice.

Limitations

This was a cross sectional study so that causality is unable to be established. CBP was not assessed invasively and we used a single CBP device for all measurements. Although this device has been validated [18], it will be important to replicate these results across other device vendors to ensure no variability exists. LA and LV strain were both measured using speckle tracking. This was performed offline using an LV algorithm. There are currently differences in the algorithm used amongst software vendors as well as differences in nomenclature and ECG gating. Despite recent attempts at creating normal reference values for LA strain [29] and standard consensus guidelines [30], further studies are warranted to assess the generatability of our results. Our findings do not necessarily mean long-term target organ damage. Rather, we aimed to identify the non-invasive method for CBP closest to true afterload to the heart as we know that the arterial pressure at the time of measurement directly influences strain at that particular time [31]. Our results demonstrated that the MAP-derived CBP affects heart function more than the standard CBP. Therefore, future study using MAP-derived CBP to guide the initiation or adjustment of the anti-hypertensive medications would be warranted.

Conclusion

CBP calibrated using MAP and DBP may be more closely associated with LA and LV function than standard brachial calibration methods. MAP-derived central SBP can be used as a sensitive screening tool to detect functional target organ damages from hypertension.
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