



Noninvasive method to validate the variability of blood pressure during arrhythmias

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For the management of hypertension, cuff-based non-invasive blood pressure (BP) measurement has established accuracy and is widely used in various settings (e.g., office, home, and ambulatory conditions). All BP values measured by this technique provide both the information necessary for an accurate diagnosis of hypertension and prognostic power for cardiovascular disease (CVD) events, and the reduction of high BP levels leads to the prevention of CVD events [1]. In addition, various BP variability parameters, such as short-, mid-, and long-term variability assessed by office BP, home BP, and ambulatory BP monitoring, are associated with the progression of target organ damage and a risk of CVD events, independent of the patients' average BP values [2–4]. However, the evidence underlying these associations was obtained in studies of populations without arrhythmia or in investigations that ignored the contribution of arrhythmias, since the device used for the BP measurements had been validated only under sinus rhythm.

Each BP value is obtained from the pulse wave from the time point at which the cuff is inflated to the time it is deflated. The values may be affected by the temporal variation and magnitude variation of the pulse wave associated with the irregularity of the heartbeats. The cardiac cycle consists of systolic and diastolic phases, and if ventricular contractility is normal, circulatory dynamics are regulated by left ventricular (LV) ejection during the systolic phase and LV filling during the diastolic phase, in addition to vascular elasticity. Fluctuations in heart rate affect LV stroke volume. Moreover, ventricular arrhythmias are prone to decrease BP because of the loss of atrioventricular (AV) contractile linking by antegrade AV node conduction.

The length of time from the QRS complex in electrocardiography monitoring to the maximum pulse wave in the peripheral arteries was defined as the conventional pulse transit time (cPTT) [5, 6], and this time variable has been used in a novel cuffless form of continuous BP monitoring. Miao et al. reported a parameter that can be used for accurate assessment of BP variability during ventricular arrhythmia based on the concept of the cPTT, and they reported that adjusted $PTT = cPTT^2/R-R$ was calculated from the R-R interval of the cardiac cycle during ventricular arrhythmias [7]. In that study, there was a strong negative correlation between the adjusted PTT and the BP assessed by an invasive method during ventricular arrhythmia compared to cPTT. It is assumed that premature ventricular complex and ventricular tachycardia (VT) with a short coupled period results in insufficient LV filling and consequently a decrease in the LV stroke volume. The adjusted PTT appears to be an index that emphasizes the prolongation of the cPTT and decreased BP along with ventricular arrhythmias with a short coupled period. Miao et al. demonstrated that the adjusted PTT is useful as an index to evaluate BP during ventricular arrhythmia. However, there are several limitations regarding the adjusted PTT to consider.

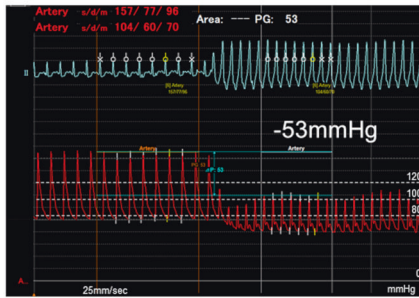
First, the adjusted PTT does not take the variation of LV contractility into account. The lowered LV contraction could decrease the magnitude of the pulse wave, which results in decreased BP values and an increased cPTT. Figure 1 shows three representative cases of catheter ablation for VT, including invasive BP measurement during VT. Each patient's case has a different etiology and illustrates the impact of LV contractility and arterial elasticity on BP during VT.

Case 1, with a normal LVEF and normal arterial elasticity, had a slight decrease in systolic BP during VT, but her pulse pressure was maintained (Fig. 1A). In contrast, in Case 2 with a reduced LVEF and normal arterial elasticity, the systolic BP and pulse pressure strikingly decreased during VT even though the cycle length of the tachycardia was longer than in the other cases (Fig. 1B).

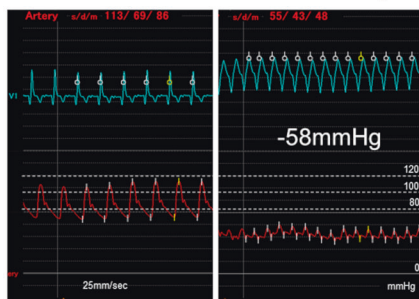
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- (A) Case 1. 39 y.o Female
Normal LVEF and Normal arterial elasticity
VT: TCL 300ms : VT rate 200bpm



- (B) Case 2. 60 y.o Male
Reduced LVEF and Normal arterial elasticity
VT: TCL 430ms : VT rate 140bpm



- (C) Case 3. 84 y.o Male
Normal LVEF and Decreased arterial elasticity
VT: TCL 300ms : VT rate 200bpm



A second consideration is that systemic arterial elasticity should also be taken into account. Increased arterial stiffness may be an important factor for the definition of cPTT because pulse wave velocity, which is the index of arterial stiffness, is included in the formula of the cPTT.

In Case 3 with a normal LVEF and decreased arterial elasticity (Fig. 1C), LV systolic function was preserved, but his systolic BP and pulse pressure were markedly decreased during VT, even though the cycle length of the tachycardia was similar to that of Case 1. Case 3 had preserved LV systolic function, but he had impaired LV relaxation abnormalities related to decreased arterial elasticity and an increased LV mass volume, leading to a decreased stroke volume.

◀ **Fig. 1 The patients' characteristics.** **A** Case 1 with normal LVEF and normal arterial elasticity. A 39-year-old female, no other etiology. VT: TCL 300, ms: VT rate 200 bpm. TTE: LVEF 70%, $E/e' = 8.4$, $E/A = 2.15$, $LVMi = 48 \text{ g/m}^2$. Stroke volume index 40.2 ml/m^2 , $LAVI 33.9 \text{ ml/m}^2$. baPWV: unknown data, possible normal. **B** Case 2 with reduced LVEF and normal arterial elasticity. A 60-year-old male, OMI, postPCI, LV apical aneurysm, DM, DLP. VT: TCL 430 ms, VT rate 140 bpm. TTE: LVEF 32%, $E/e' = 7.1$, $E/A = 0.69$, $LVMi = 226 \text{ g/m}^2$, LVH. Stroke volume index 57.8 ml/m^2 , $LAVI 62.2 \text{ ml/m}^2$. baPWV: right 1346, left 1363. **C** Case 3 with normal LVEF and reduced arterial elasticity. An 84-year-old male, IHD, postPCI, HTN, DM, CKD grade 5, DLP, HUA, prior CI. VT: TCL 300 ms, VT rate 200 bpm. TTE: LVEF 63%, $E/e' = 7.8$, $E/A = 0.60$, $LVMi = 125 \text{ g/m}^2$, LVH. Stroke volume index 43.4 ml/m^2 , $LAVI 42.3 \text{ ml/m}^2$. baPWV: right 3004, left 2755. CI cerebral infarction, CKD chronic kidney disease, DLP dyslipidemia, DM diabetes mellitus, HTN hypertension, HUA hyperuricemia, IHD ischemic heart disease, $LAVI$ left atrial volume index, LVEF left ventricular ejection fraction, LVH left ventricular hypertrophy, $LVMi$ left ventricular mass index, OMI old myocardial infarction, PCI percutaneous coronary intervention, PWV pulse wave velocity, TCL tachycardia cycle length, TTE transthoracic echocardiography, VT ventricular tachycardia.

There are thus multiple factors (such as LV contractility including both systolic and diastolic function and arterial elasticity) that affect BP variability during arrhythmias, in addition to the irregularity of heart rate.

Third, the consistency between the adjusted PTT parameter and BP levels measured by noninvasive BP monitoring has not been validated. However, this issue is applicable for not only adjusted PTT but also other cuffless wearable BP monitoring device methods that include cPTT, and the assessment of the accuracy of these BP measurement devices requires the use of a validation protocol.

Although atrial fibrillation (AF) does not cause hemodynamic changes compared to ventricular arrhythmia, the number of patients with AF has been increasing, and AF is one of the arrhythmias for which hypertension is a major complication; in addition, AF is associated with a risk of thrombotic events and incident heart failure [8, 9]. We reported the specific shape of the oscillometric curve and arrhythmia characteristics due to the intracuff pressure waveform during cuff contraction in oscillometric BP measurement with a new BP monitoring device [10]. It is also important to assess the impact of heart rate variability on BP variability during arrhythmias by determining the patterns of the oscillometric curve and intracuff pressure waveform. Especially in patients with AF, it is known that BP variability is caused by fluctuations in the heart rate and diastolic phase with a loss of atrial kick and LV filling, and BP variability is induced by variability in the cardiac output, resulting in a “pulse deficit.” Accurate assessments of BP indices in patients with AF along with irregularity in the R-R interval must also take the heart rate into account, and it is necessary to verify the accuracy of the cPTT during AF.

The current validated device for BP measurements was derived from the cuff-based method. However, it is not possible to perform continuous BP measurements with this device, which may cause a burden for patients. With the further development of noninvasive cuffless BP measurement and its validation, new information for the control of BP under various conditions, including arrhythmia, could be obtained, although this presents a significant challenge [11, 12].

Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

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