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Original article

Comparison of the clinical significance of single cuff-based arterial stiffness parameters with that of the commonly used parameters

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ABSTRACT

Background: We examined the following: (1) whether the new simple markers related to the arterial stiffness/central hemodynamics [i.e. arterial pressure-volume index (API) and arterial velocity pulse index (AVI)] are clinically interchangeable with the commonly used markers [brachial-ankle pulse wave velocity (baPWV) and radial augmentation index (rAI)]; (2) whether the new simple markers reflect vascular damage as reliably as the commonly used markers; (3) which cardiovascular risk factors are reflected by these new simple markers.

Methods: API, AVI, baPWV, and rAI were measured simultaneously in consecutive patients admitted for the management of cardiovascular disease and/or cardiovascular risk factors ($n = 322$).

Results: The API was correlated with the baPWV ($R = 0.492$, $p < 0.001$) and the AVI correlated with the rAI ($R = 0.462$, $p < 0.001$). The API, AVI, baPWV, and rAI were higher in the patients admitted for coronary angiography (CAG group: $n = 152$) than in those admitted for reasons other than coronary angiography (nonCAG group: $n = 170$). After adjustments for confounding factors, only the AVI was found to be higher in the CAG group than in the nonCAG group. Multivariate linear regression analysis revealed that age and the systolic blood pressure were independently associated with the API and AVI after adjustments.

Conclusion: In patients with cardiovascular diseases or cardiovascular risk factors, the new simple markers and the commonly used markers are not interchangeable for assessing vascular damage and/or cardiovascular risk. Further study is proposed to examine whether AVI is higher in subjects with cardiovascular disease than in those without a history of cardiovascular disease. Similar to the case for the commonly used markers, age and the blood pressure significantly influenced both the new markers; therefore, age and the blood pressure need to be taken into account while interpreting the changes in these new simple markers.

Introduction

Vascular damage associated with atherosclerosis and/or aging is associated with increase in arterial stiffness and abnormal pressure wave reflection in the arterial tree [1–3]. Arterial stiffness and the pressure wave reflection associated with it have received much attention as independent risk factors for cardiovascular disease [1–3]. Conventionally, carotid-femoral pulse wave velocity (cfPWV) and aortic augmentation index (aAI) have been used as markers to reflect these pathophysiological abnormalities [1–3]. Furthermore, markers that are even simpler to measure, such as brachial-ankle PWV (baPWV) and radial AI (rAI), have also become available as commonly used markers [4]. Even so, since the number of subjects who need clinical application of these markers is large, simpler-to-measure markers have been sought. Then, recently, arterial pressure-volume index (API) and arterial velocity pulse index (AVI), which are obtained by pressure wave analysis of the brachial pulse waves recorded with a regular brachial oscillometric blood pressure cuff, have become available for use in clinical settings [5,6]. API is thought to be related to the PWV and AVI is thought to be related to the AI. However, it remains to be fully validated as to whether these new simple markers are sufficiently robust to reflect vascular damage, and it remains unclear as to which cardiovascular risk factors they might be related to.

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In the present cross-sectional study, we measured these new simple markers (API and AVI) and the commonly used markers (baPWV and rAI) simultaneously in consecutive patients admitted for the management of cardiovascular disease and/or cardiovascular risk factors. We examined the following: (1) whether the new simple markers are clinically interchangeable with the commonly used markers (baPWV and rAI) for assessing the risk of cardiovascular disease; (2) whether these new simple markers reflect vascular damage as reliably as the commonly used markers; (3) which cardiovascular risk factors are reflected by these new simple markers.

Methods

Study participants

From February 1st 2014 to August 31st 2014, 352 consecutive patients were hospitalized to the cardiology department of Tokyo Medical University Hospital for the management of their disease. They were divided into two groups, one group of patients admitted for coronary angiography [i.e. diagnosis/treatment (angioplasty) of coronary artery disease] (CAG group) and another admitted for reasons other than angiography [i.e. management (diagnosis/treatment) arrhythmia or sleep disorders] (nonCAG group). Some of the patients of the CAG group had confirmed significant coronary artery stenosis by the previous coronary angiography, while in other patients of the same group, coronary angiography was recommended based on the results of electrocardiographic stress testing or cardiac scintigraphy carried out for coronary artery disease screening. Patients admitted for the management of cardiac emergencies, such as acute coronary syndrome, acute exacerbation of heart failure, infectious diseases, etc., were excluded from the study. The study was conducted with the approval of the Ethics Committee of Tokyo Medical University. Written informed consent was obtained from each subject before enrollment in the study.

Study design and measurements

On the day of admission, after at least 15 minutes' rest, first the AVI/API, then the rAI and finally, the baPWV were measured. The measurements of the API/AVI and baPWV/rAI were conducted in the afternoon, and the patients were requested to abstain from food intake for at least 2 h before the measurements.

Arterial pressure-volume index (API) and arterial pressure-volume index (API)

The API, AVI, systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), and heart rate (HR) were measured simultaneously based on the brachial pulse waves recorded with a regular brachial oscillometric blood pressure cuff (Pasesa AVE-1500, Shisei Datum, Yokohama, Japan) with the subjects in the sitting position. Details of measurement of both the parameters are described elsewhere [5,6]. Briefly, a conventional blood pressure cuff was wrapped around the left upper arm and inflated to 190 mmHg at the rate of 10 mmHg/s, and deflated to 10 mmHg at the rate of 3 mmHg/s. Cuff pressures during inflation and deflation measured using a pressure transducer were stored. Using the amplitudes of all the pulse oscillations and changes in the cuff pressure for pulse pressure from the pressure point evoked by the pulses, we calculated the local slopes of the curve between the cuff pressure and the arterial volume. We calculated the numerical integration of the averaged slopes to generate pressure-volume curves and identified a numerical coefficient of the equation as API. Thus, API is thought to be a marker of the local arterial stiffness. AVI shows the characteristics of the pulse waveform when the cuff pressure is higher than the maximum blood pressure. Based on the cuff pressure waveforms, the differentiated waveforms of the forward pressure wave (Vf) and reflected pressure wave were (Vr) obtained. Then, the AVI was calculated as $20 \times Vr/Vf$. Thus, AVI is thought to be a marker of the pressure wave reflection.

Brachial-ankle pulse wave velocity and radial augmentation index

With the subject in the sitting position, the left radial arterial waveform was recorded using an arterial applanation tonometry probe equipped with an array of 40 micropiezo-resistive transducers (HEM-9010AI; Omron Healthcare Co., Ltd., Kyoto, Japan). The HEM-9010AI device is programmed to automatically determine the pressure of the radial artery to yield the optimal radial arterial waveform [7]. Then, the first and second peaks of the peripheral systolic pressure (SBP1 and SBP2) and peripheral diastolic pressure (DBP) were automatically detected using the fourth derivatives for each radial arterial waveform, and averaged. The rAI was calculated as follows: $(SBP2 - DBP)/(SBP1 - DBP) \times 100$ (%) [7].

The baPWV was measured using a volume-plethysmographic apparatus (Form/ABI, Colin Co. Ltd., Komaki, Japan), in accordance with a previously described methodology [8]. In brief, occlusion cuffs, connected to the plethysmographic and oscillometric sensors, were tied around both the upper arms and ankles of the subjects lying in the supine position. The brachial and post-tibial arterial pressures were measured using the oscillometric sensor.

Laboratory measurements

The serum levels of low-density lipoprotein cholesterol (LDL), high-density lipoprotein cholesterol (HDL), triglyceride (TG), and creatinine (Crnn), and glycohemoglobin A1c (HbA1c) were measured enzymatically. The estimated glomerular filtration rate (eGFR) was calculated using the Modification of Diet in Renal Disease equation for Japanese subjects {194 × [serum creatinine concentration]$^{-1.094}$ × [age]$^{-0.287}$ (× 0.739 for women)} [9].

Statistical analysis

Data are expressed as means ± SD (standard errors are depicted in the figures). Categorical data are expressed as percentages and compared by the chi-square test. For assessment of the differences in the status of each variable among the groups, one-way analysis of variance and the Kruskal–Wallis test were applied. In addition, the difference was also assessed by a general linear model univariate analysis with adjustments. Pearson correlation analyses were used to investigate the linear relationship between API and baPWV and that between AVI and rAI. For assessment of the significance of relationships among the variables, univariate linear regression analysis was conducted. Then, a multivariate linear regression analysis was conducted to identify the strength of the significance of the relationship. All of the analyses were conducted using the IBM/SPSS software for Windows, version 23.0J (IBM/SPSS Inc., Chicago, IL, USA); p-values <0.05 were considered to denote statistical significance.

Results

Among the 352 consecutive study subjects, 30 subjects [ankle-brachial pressure index <0.90 (n = 19), atrial fibrillation (n = 5) and left ventricular ejection fraction <40% (n = 6)] were excluded from the analysis. Finally, the analyses were conducted in 322 patients. Pearson correlation analyses demonstrated a significant, but not strong, correlation between the API and baPWV and that between the AVI and rAI (Fig. 1).