A Comparison of the Approaches to Assess the Abdominal Aortic Stiffness Using M-mode Ultrasonography, Tissue Tracking and Strain Rate Imaging

Xiao-Zhi Zheng,[1,2] Bin Yang,[1] Jing Wu[2]

[1]Department of Ultrasound, Jinling Hospital, Nanjing University School of Medicine, Nanjing City, Jiangsu Province, China,
[2]Department of Ultrasound, The Fourth Affiliated Hospital of Nantong University, Jiangsu Province, China.

ABSTRACT

Introduction: Which kind of ultrasound imaging technique is suitable for the assessment of the abdominal aortic stiffness are seldom reported. The purposes of this study were to explore a reliable method to evaluate the abdominal aortic stiffness in patients with hypertension among the following ultrasound imaging techniques: M-mode ultrasonography (M-mode), tissue tracking and strain rate imaging.

Methods: Fifty patients with hypertension and fifty age and sex-matched healthy volunteers were involved in this study. The displacement (d), the peak strain (ε) and the peak strain rate (s) were obtained from the long-axis images of the abdominal aorta using tissue tracking and strain rate imaging, respectively. The pressure strain elastic modulus (Ep), β stiffness index and distensibility were calculated according to the conventional formulas using M-mode combined with the blood pressure.

Results: Compared to the normal subjects, the difference between systolic diameters and diastolic diameters (Δdiameter), the displacement of posterior wall (d-posterior), the difference of the displacement between anterior and posterior wall (Δ displacement), and the distensibility decreased and the Ep and β stiffness index increased in the hypertension patients There were no significant differences between the patients with hypertension and the normal subjects according to the ε, s. Among Δdiameters, d-posterior, Δdisplacement, the ε and s, only Δdiameters significantly correlated with the Ep, β stiffness index and the distensibility in hypertension patients.

Conclusions: Strain rate imaging cannot sensitively discriminate the difference of the abdominal aortic stiffness between patients with hypertension and the normal subjects. M-mode ultrasonography is still a classical method for accessing the aortic elasticity.

Keywords: *abdominal aortic elasticity; hypertension M-mode ultrasonography; strain rate imaging; tissue tracking.*

INTRODUCTION

Hypertension is one of the most common cardiovascular diseases characterized by a basic lesion, systemic arterial stiffness. Pathological studies showed that

Correspondence: Bin Yang, Department of Ultrasound, Jinling Hospital, Nanjing University School of Medicine, 305 East Zhongshan Road, 210002, Nanjing City, Jiangsu Province, China. Email: yb12yx@hotmail.com, Phone: +8625-80861314.

aortic lesions including stiffness and arteriosclerosis in the abdominal aorta are most serious, and that they are usually consistent with the degree of coronary atherosclerosis.[1] More and more studies demonstrate that arterial stiffening have a direct impact on prognosis in patients with a series of so-called 'vascular disease', such as arterial hypertension, diabetes, coronary heart disease, brain stroke and so on. To date, aortic stiffness has been recognized as an independent risk factor for major adverse cardiac and cerebrovascular events.[2-4]

Up to now, there are several non-invasive imaging techniques available for the detection of subclinical changes in structural and mechanical properties of the arteries in clinical practice. For example, dynamic magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound imaging techniques all play an important part in this aspect. But some limitations like MRI and CT for instance, are still expensive and not readily available. The appearance of ultrasonography may be solve this problem, which facilitates a fast, simple, accurate and low-cost measurement of the structural and mechanical properties in the arteries.

At present, the ultrasonographic methods of assessment of the artery stiffness include: 1) The estimation of vascular stiffness from distending pressure and diameter measurements using M-mode ultrasonography (M-mode) in combination with the blood pressure, such as the pressure strain elastic modulus (Ep), β stiffness index and distensibility. 2) Analysis of vascular motion and deformation variables, such as velocity using tissue velocity imaging (TVI), displacement using tissue tracking (TT), strain and strain rate using strain rate imaging (SRI).[6-11] Each approaches has individual features.

Although some studies show that the peak strain (ε) and peak strain rate (s) are correlated strongly with age and can discriminate the difference between the younger and older age groups.[9,11] So SRI is recognized as a superior technique to the conventional M-mode, the comparison of M-mode and TT, SRI for assessing the abdominal aortic stiffness in patients with hypertension are seldom reported.

In the present study, M-mode, TT and SRI were performed in 50 hypertension patients and 50 normal subjects. The displacement (d), (ε) and (s) of the abdominal aorta were compared between the patients with hypertension and the normal subjects, and the correlations between the d, ε, s and the Ep, β stiffness index and distensibility were investigated using the linear correlation analysis in order to explore a reliable method to evaluate the abdominal aortic stiffness in the hypertension patients.

METHODS

The study was approved by the local human research ethics committee and informed consent was obtained from all the study patients. The blood pressure that is greater than or equal to 140/90 mmHg is diagnosed as hypertension based on the guidelines of the seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC-7).[12] The study population consisted of 50 patients with hypertension (26 males and 24 females, mean age: 46.9 ± 18.17 years, range: 27–83 years) who did not suffer from aortic disease, diabetes, renal disease, known coronary artery disease, previous stroke, chronic obstructive pulmonary disease. Meanwhile, 50 age and sex-matched normal subjects (26 males and 24 females, mean age: 45.19 ± 15.4 years, range: 22–80 years) were recruited as the control group who were confirmed as healthy individuals by health check-up.

A commercially available ultrasonic system (Vivid 7; General Electric Medical Systems, Milwaukee, WI, USA) equipped with Q-analyze quantitative analysis software for TVI, TT and SRI and a harmonic 1.7-3.4 MHz variable frequency phased array transducer were used in this study. First, a two dimensional image of long-axis view of the abdominal aorta at a level 3 cm below the renal arteries was acquired at a frame rate of 100 frames per second. The diameter and pulsatile diameter changes of the abdominal aorta were measured by means of M-mode. The systolic diameters (Dd), diastolic diameters (Dd) of three successive cardiac cycles were obtained. The conventional parameters, i.e., Ep, β stiffness index and distensibility were calculated according to the following formulas by a combinatorial use of M-mode and the blood pressure. [6-9]

$$Ep = K \times (SBP - DBP)/[(Ds - Dd)/Dd]$$

$$\beta \text{stiffness index} = \ln (SBP/DBP)/[(Ds - Dd)/Dd]$$

$$\text{distensibility} = [2(Ds\text{-}Dd)/Dd(SBP\text{-}DBP)] \times 10^{-6}\ cm^2 dyn^{-1}$$

In these equations, SBP and DBP are the systolic blood pressure and diastolic blood pressure (mmHg). Ep is measured in newton per square meter. The factor (K) for converting millimeters of mercury to newton per square meter is 133.3.

Second, the TVI function was activated and the TVI of three cardiac cycles in the long-axis view of the abdominal aorta at a level 3 cm below the renal arteries was stored at a frame rate of 100 frames per second for subsequent analysis. In this process, gains were adjusted at the minimal optimal level to minimize noise, and the filter settings were kept low (50 Hz). Finally, a region of interest was placed to cover the cross-sectional area of the abdominal aorta wall for measurements of displacement and strain variables. Adequate tracking of the vessel wall was verified and, if necessary, adjusted. The d, ε and s were obtained from the long-axis images of the abdominal aorta using TT and SRI, respectively (Figure 1). All values for each parameter were obtained by averaging measurements from three successive cardiac cycles.

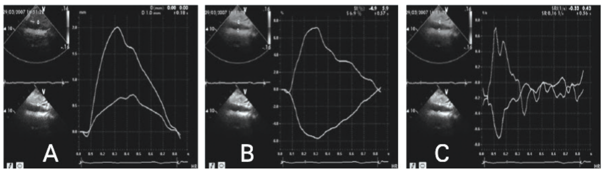

Figure 1. Measurement methods of tissue tracking and strain rate imaging. The image was obtained from the long-axis view of the abdominal aorta. A. peak displacement determined by aortic displacement curve; B. peak strain determined by aortic strain curve; C. peak strain rate determined by aortic strain rate curve.

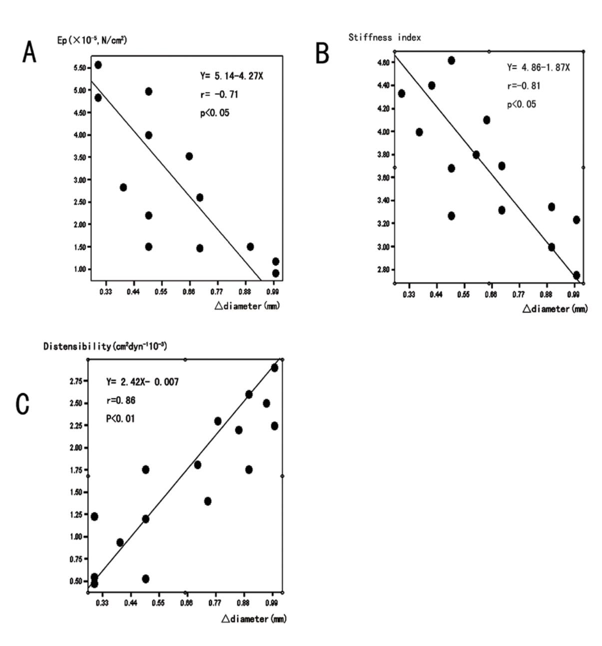

Figure 2. Correlations between the Ep (A), Stiffness index (B), distensibility (C) and the diameter.

Intraobserver variability was assessed in 30 patients (15 in normal subjects and 15 patients with hypertension) by repeating the measurements on two occasions (seven days apart) under the same basal conditions. To test the inter observer variability, the measurements were performed offline from video recordings by a second observer who was unaware of the results of the first examination. Variability was calculated as the mean percentage error, derived as the difference between the two sets of measurements, divided by the mean observations.

The values were expressed as the mean ± SD. Differences between the mean values of the two groups were analyzed by the one-way analysis of variance (ANOVA). The Pearson linear correlation analysis was used for determining the significance of correlations between variables, such as d, ε, s and Ep, β stiffness index and distensibility. Differences were considered significant at $p<0.05$. SPSS version 13 (SPSS, Chicago, IL, USA) was used for all statistical analysis.

RESULTS

There were no significant differences between the patients with hypertension and the normal subjects according to age, sex, body mass index (BMI), heart rate and left ventricular ejection-fraction (LVEF) (Table 1). The SBP, DBP and pulse pressure (PP) of the patients with hypertension were visible greater than that of the normal subjects.

Table 1. Clinical characteristics of patients with hypertension and control subjects.

Clinical features	Control, mean (SD)	Patients, mean (SD)	P-value
Age (years)			
Sex (female/	69.31(6.12)	68.81(7.53)	0.76
male)	26/24	26/24	0.63
BMI (kg/m²)	19.58 (1.73)	20.62 (2.29)	0.72
Heart rate	73.42(5.64)	71.97(6.14)	0.0015
(min⁻¹)	115.94(13.17)	157.63(28.45)	0.037
SBP (mmHg)	75.62(11.92)	88.65(12.53)	0.0014
DBP (mmHg)	38.75(6.61)	68.69(21.94)	0.53
PP (mmHg)	69.85(9.33)	71.64(10.47)	
LVEF (%)			

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; LVEF, left ventricular ejection-fraction

The patients with hypertension and the normal subjects did not differ in Ds and Dd (Table 2). Compared to the healthy subjects, the difference between systolic diameters and diastolic diameters (diameter), the displacement of posterior wall (d-posterior), the difference of the displacement between anterior and posterior wall (displacement) and the distensibility (Dis) decreased and the Ep and β stiffness index increased in the hypertension patients There were no significant differences between the patients with hypertension and the normal subjects according to the ε, s.

Table 2. Comparison of abdominal aortic ultrasonographic data between patients with hypertension and normal subjects.

Variables	Normal, mean (SD)	Patients, mean (SD)	P-value
Ds (mm)	13.23(3.34)	14.26(2.92)	0.3757
Dd (mm)	11.91(3.53)	13.74(2.95)	0.2382
diameter (mm)	1.15(0.54)	0.62(0.33)	0.0091
Anterior wall			
Displacement (mm)	0. 96(0.62)	0.83(0.56)	0.7722
ε (%)	1.93(0.7)	2.25(1.19)	0.4286
s(s-1)	-0.28(0.19)	-0.35 (0.26)	0.8333
Posterior wall			
Displacement (mm)	0.64(0.52)	0.41(0.27)	0.013
ε (%)	3.23(2.27)	4.54(3.62)	0.314
$s(s^{-1})$	0.62(0.43)	0.54 (0.37)	0.622
displacement(mm)	0.43(0.19)	0.25(0.13)	0.035
Ep ($\times 10^{5}$, N/m^{2})	1.14(0.96)	2.65((1.78)	0.015
βStiffness index	2.92(0. 78)	3.89(0.62)	0.023
Dis($cm^{2}dyn^{-1}$ 10^{-3})	5.23(3.21)	1.46(0.83)	0.001

Ds, systolic diameter; Dd, diastolic diameter; Δdiameter, the difference of systolic diameter and diastolic diameter; ε, peak strain; s, peak strain rate; Ep, pressure strain elastic modulus; Δdisplacement, the difference of the displacement of anterior and posterior wall; Dis, distensibility.

The Pearson linear correlation analysis showed that diameters correlated strongly with Ep, β stiffness index and the distensibility in patients with hypertension. But, there was no significant correlation between the d-posterior, displacement, ε and s and the Ep, β stiffness index and the distensibility

Table 3. The Pearson correlation analysis between the Δdiameter, d-posterior, Δdisplacement, ε, s and Ep, βStiffness index, distensibility in patients with hypertension.

Variables	Ep, r(p)	Stiffness index, r(p)	Dis, r(p)
Δdiameter	-0.71(0.02)	-0.81(0.02)	0.86(0.01)-
d-posterior	0.39(0.23)	0.58(0.08)	0.28(0.42)
Δdisplacement	0.23(0.51)	0.25(0.34)	0.01(0.98)
Anterior wall			
ε	0.024(0.95)	0.29(0.39)	0.173(0.61)
s		0.04(0.91)	0.15(0.65)
Posterior wall			
ε	0.17(0.61)	0.31 (0.37)	0.24(0.48)
s	0.15(0.67)	0.46(0.15)	0.29(0.43)

Δdiameter, the difference of systolic diameter and diastolic diameter; r, pearson correlation coefficient; p, p-value calculated by t test; d-posterior, the displacement of posterior wall; Δdisplacement, the difference of the displacement of anterior and posterior wall; Dis, distensibility.

Intraobserver and interobserver variability for diameters, displacements ranged from 2.9% to 5.7%. Intraobserver and interobserver variability for the ε were 4.9% ± 2.3%, 6.1% ± 3.4%, respectively. Intraobserver and interobserver variability for the s were 5.7% ± 2.4% and 7.4% ± 1.5%, respectively.

DISCUSSION

The aortic elasticity determines large vessel 'Windkessel' function, systolic arterial pressure and left ventricular afterload.[13] It is necessary to study the aortic elasticity for its important physiological significance. Distensibility is a marker for aortic elasticity, while Ep and β stiffness index are conventional markers for aortic stiffness. Abnormality in these parameters means the changes in the structure and mechanical behavior of the arterial system.[8,14]

Hithreto, M-mode ultrasonography have been widely used in clinical settings because of its excellent temporal resolution, which make it be able to accurately measure the cardiac sizes and vascular diameters. The conventional parameters of aortic elasticity or stiffness, distensibility, Ep and β stiffness index that origin from M-mode have been shown to serve as good predictors for the cerebrovascular or cardiovascular lesions,[2-5,15] although its limitations, such as the complex calculation methods and the influence of blood pressure, have been proposed.[9] TT and SRI were previously applied in the assessment of myocardial function.[16,17] Now, they have been attempted to assess the arterial elasticity or stiffness in healthy individuals, such as abdominal aorta and carotid artery.[9,11] However, which one is suitable for the assessment of the abdominal aortic stiffness in patients with hypertension remains unknown.

Our results indicated that the patients with hypertension and the normal subjects did not differ in ε and s, and the ε and s did not correlate with the Ep, β stiffness index and the distensibility in patients with hypertension. However, the diameter significantly decreased in the patients with hypertension, which correlated strongly with the Ep, β stiffness index and the distensibility. This indicates that SRI is not more sensitive than M-mode for discrimination the difference of the abdominal aortic stiffness between patients with hypertension and the normal subjects.

In patients with hypertension, increased blood pressure may have more influences on arterial stiffness, so it is reasonable to evaluate the arterial elasticity or stiffness using the conventional parameters calculated by M-mode ultrasonographic parameters and blood pressure, such as Ep, βstiffness index and the distensibility, while TT and SRI only reflect the vascular motion and deformation. In addition, TT and SRI cannot effectively capture the echo signal from the measured site of deep vessels such as abdominal aorta compared to M-mode ultrasonography, they are less accurate due to decreased spatial resolution.

CONCLUSIONS

Our study demonstrate that M-mode ultrasonography can still be employed to discriminate the difference of the abdominal aortic stiffness between patients with hypertension and the normal subjects, and that SRI is not always superior to the conventional M-mode ultrasonography. This suggests that different approaches for the assessment of arterial elasticity or stiffness should be selectively applied in different diseases.

ACKNOWLEDGEMENTS

This work was supported by Yancheng second batch of health science and technology projects, Jiangsu province, P.R.China (Grant No.YK2006120) and acknowledge technical assistance and helpful discussion of Xia EH, Jiang XL, Lin L, Wang JW, Qiao XL at the department of ultrasound, The First People's Hospital of Yancheng, Jiangsu Province, P.R. China.

REFERENCES

1. Li YL. Pathology. 6th ed. Beijing: The people's health press; 2005. p. 131-5.
2. Boutouyrie P, Tropeano AI, Asmar R, Gautier I, Benetos A, Lacolley P, et al. Aortic stiffness is an independent predictor of primary coronary events in hypertensive patients: a longitudinal study. Hypertension. 2002 Jan;39(1):10-5.
3. Stefanadis C, Dernellis J, Tsiamis E, Stratos C, Diamantopoulos L, Michaelides A, et al. Aortic stiffness as a risk factor for recurrent acute coronary events in patients with ischaemic heart disease. Eur Heart J. 2000 Mar;21(5):390-6.
4. Orlova IaA, Ageev FT. Arterial stiffness as a predictor of cardiovascular events in coronary heart disease. Ter Arkh. 2010;82(1):68-73.
5. Yildiz A, Gur M, Yilmaz R, Demirbag R. The association of elasticity indexes of ascending aorta and the presence and the severity of coronary artery disease. Coron Artery Dis. 2008 Aug;19(5):311-7.
6. Pannier BM, Avolio AP, Hoeks A, Mancia G, Takazawa K. Methods and devices for measuring arterial compliance in humans. Am J Hypertens. 2002 Aug;15(8):743-53.
7. Powell JT, Turner RJ, Sian M, Debasso R, Lanne T. Influence of fibrillin-1 genotype on the aortic stiffness in men. J Appl Physiol. 2005 sep;99(3):1036-40.
8. Gedikli O, Altinbas A, Orucoglu A, Dogan A, Ozaydin M, Aslan SM, et al. Elastic properties of the ascending aorta in patients with β-thalassemia major. Echocardiography. 2007 sep;24(8):830-6.
9. Oishi Y, Mizuguchi Y, Miyoshi H, Iuchi A, Nagase N, Oki T. A novel approach to assess aortic stiffness related to changes in aging using two-dimensional strain imaging. Echocardiography. 2008 Oct;25(9):941-5.
10. Levent E, Atik T, Darcan S, Ülger Z, Göks D, Özyürek AR. The relation of arterial stiffness with intrauterine growth retardation. Pediatr Int. 2009 Dec;51(6):807-11.
11. Bjallmark A, Lind B, Peolsson M, Shahgaldi K, Brodin LA, Nowak J. Ultrasonographic strain imaging is superior to conventional non-invasive measures of vascular stiffness in the detection of age-dependent differences in the mechanical properties of the common carotid artery. Eur J Echocardiogr. 2010 Aug;11(7):630-6.
12. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL Jr, et al. The seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. JAMA. 2003 May 21;289(19):2560-72.
13. Studinger P, Lénárd Z, Reneman R, Kollai M. Measurement of aortic arch distension wave wih the echo-track technique. Ultrasound Med Biol. 2000 Oct;26(8):1285-91.
14. Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D, et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur Heart J. 2006 Nov;27(21):2588-605.
15. Levent E, Ozyürek AR, Ülger Z. Evaluation of aortic stiffness in tobacco-smoking adolescents. J Adolesc Health. 2004 Apr;34(4):339-43.
16. 16. Abraham TP, Nishimura RA, Holmes DR, Belohlavek M, Seward JB. Strain rate imaging for assessment of regional myocardial function: results from a clinical model of septal ablation. Circulation. 2002 Mar;105(12):1403-6.
17. Sutherland GR, Salvo GD, Claus , D'hooge J, Bijnens B. Strain and strain rate imaging: a new clinical approach to quantifying regional myocardial function. JASE. 2004 Jul;17(7):788-802.