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Original Article

Role of ultrasonography in the evaluation of correlation between strain and elasticity of common carotid artery in patients with diabetic nephropathy

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Abstract: Objective: This study aimed to investigate the correlation between strain and elasticity of the common carotid artery (CCA) by ultrasonography and evaluate its clinical significance in patients with diabetic nephropathy (DN). Methods: A total of 68 DN patients and 54 healthy subjects were randomly recruited from the Ultrasound Department from April 2014 to March 2015. The maximum of circumferential strain (CSmax), maximum of circumferential strain rate (CSRmax), compliance coefficient (CC) and stiffness index (β) of the CCA were determined by ultrasonography in all the patients, and correlation analysis was performed. Results: The CC, CSmax and CSRmax in DN group were significantly lower than in healthy controls ($P<0.05$), but β was markedly higher than in control group ($P<0.05$). There was a significantly positive correlation of CSmax and CSRmax with CC and a negative correlation with β in both control group and DN group. Conclusion: There is significant correlation between strain and elastic of the CCA. CSmax and CSRmax may be used to reflect the mechanical characteristics of CCA.

Keywords: Diabetic nephropathy, vascular complications, common carotid artery, strain, elasticity

Introduction

The elasticity related parameters such as compliance coefficient (CC) and stiffness index (β) can objectively reflect the stiffness of arteries [1, 2] and may be used to clinically evaluate the arterial elasticity in the early stage of a disease. Thus, increasing studies pay attention to the arterial elasticity in humans [3-5]. In recent years, with the application of ultrasonography and the up-dating of corresponding software, clinicians are easy and accurately acquire these elasticity related parameters via instruments [6, 7]. However, studies on the arterial strain are still in their infant stage. There is evidence showing that arterial strain can be used to reflect the arterial deformation and then to evaluate the arterial movement [8]. Since elasticity and strain may reflect the mechanical and motion characteristics of arteries, whether there is correlation between them is still unclear. This study was undertaken to investigate the correlation between elasticity and strain of the common carotid artery in patients with diabetic nephropathy (DN).

Materials and methods

Patients and healthy controls

A total of 68 patients with DN were recruited from the Ultrasound Department of our hospital between April 2014 and March 2015. DN was diagnosed according to the Tervaert criteria [9]. There were 26 males and 42 females and the median age was 45.26±12.89 years (range: 34-60 years). Vascular diseases secondary to hypertension, cardiac dysfunction and other endocrine diseases were excluded. In the same period, healthy subjects (n=54) were recruited

Table 1. Basic information of DN patients and healthy subjects

Group	n	Age (year)	SBP (mmHg)	DBP (mmHg)	HR (bpm)	BMI (kg/m^2)	LVEF (%)	SV (ml)
Control	54	45.98±13.02	116.81±12.98	70.82±9.77	68.14±11.03	20.98±2.88	65.46±8.72	73.02±9.68
DN	68	45.26±12.89	113.47±12.65	72.34±9.86	70.21±11.92	21.76±2.95	63.23±8.63	70.35±9.46

Note: SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HR: Heart Rate; BMI: Body MassIndex; LVEF: Left Ventricular Ejection Fraction; SV: Stroke Volume.

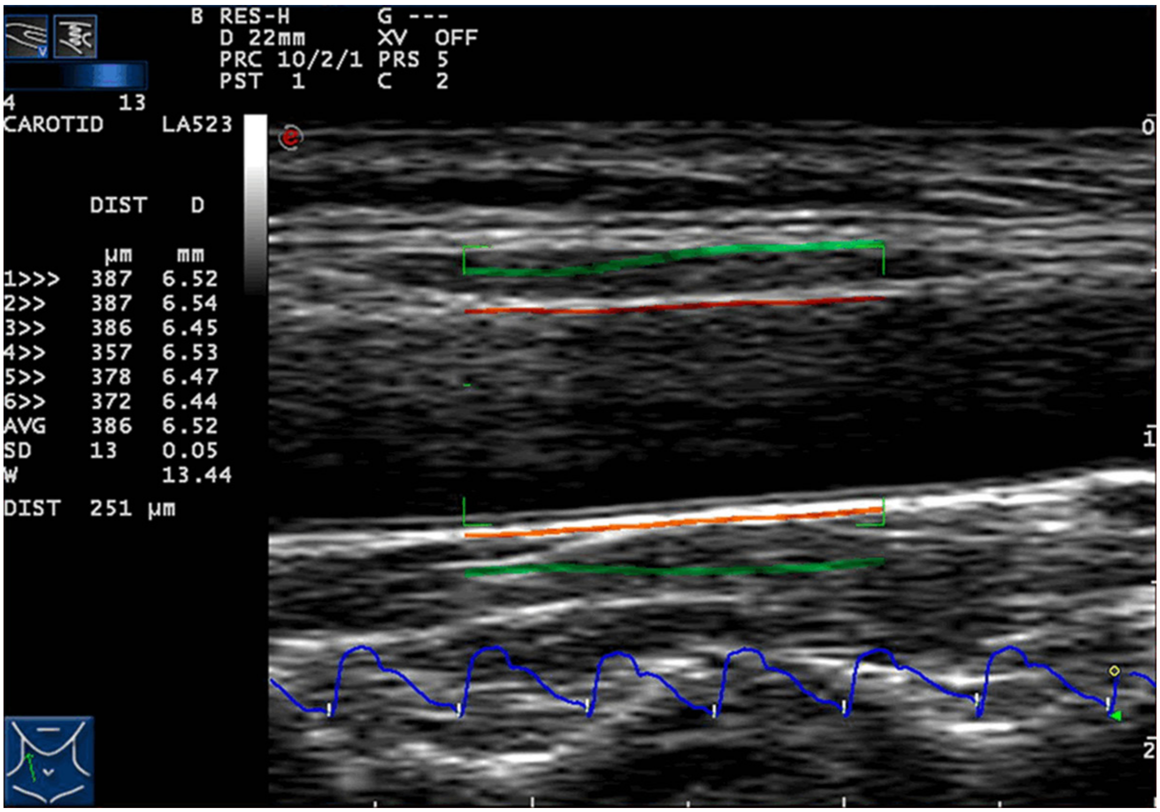


Figure 1. Elasticity related parameters of right CCA. The width of sampling frame was 1.4-1.5 cm, the location and height of sampling frame were adjusted, the probe was fixed, and patients were asked to hold the breath. When 6 stable vascular dilations were present on the screen (standard deviation ≤15), the images were frozen.

as controls. There were 24 males and 30 females and the median age was 45.98±13.02 years (range: 30-62 years) (**Table 1**). Coffee and alcohol were not administered within 24 h before examination.

Instruments and methods

Mylab90 ultrasound scanner (Esaote, Italy) was used in this study with LA523 probe and its frequency of 4-13 MHz. There is supporting software used to measure the elasticity and strain of CCA.

The blood pressure and heart rate were measured routinely, and the patients' characteristics (gender, birth date and blood pressure) were input into the ultrasound scanner. Patients were asked to lie in supine position and the neck was completely exposed. The electrocardiogram was measured during the whole ultrasonography. The CCA was scanner transversally and longitudinally to identify the arterial plaques. Once arterial plaques were present, patients were excluded from this study. The arterial plaques were determined according to the criteria of Salcumiet al [10]: The increase in the thickness of the intima-media thickness (IMT) of focal CCA by >1.2 mm is used to define the arterial plaque. The target artery was from 1.5 cm above the beginning part of CCA to 1.5 cm below the bifurcation of CCA.

Measurement of the elasticity related parameters of right CCA: The width of sampling frame

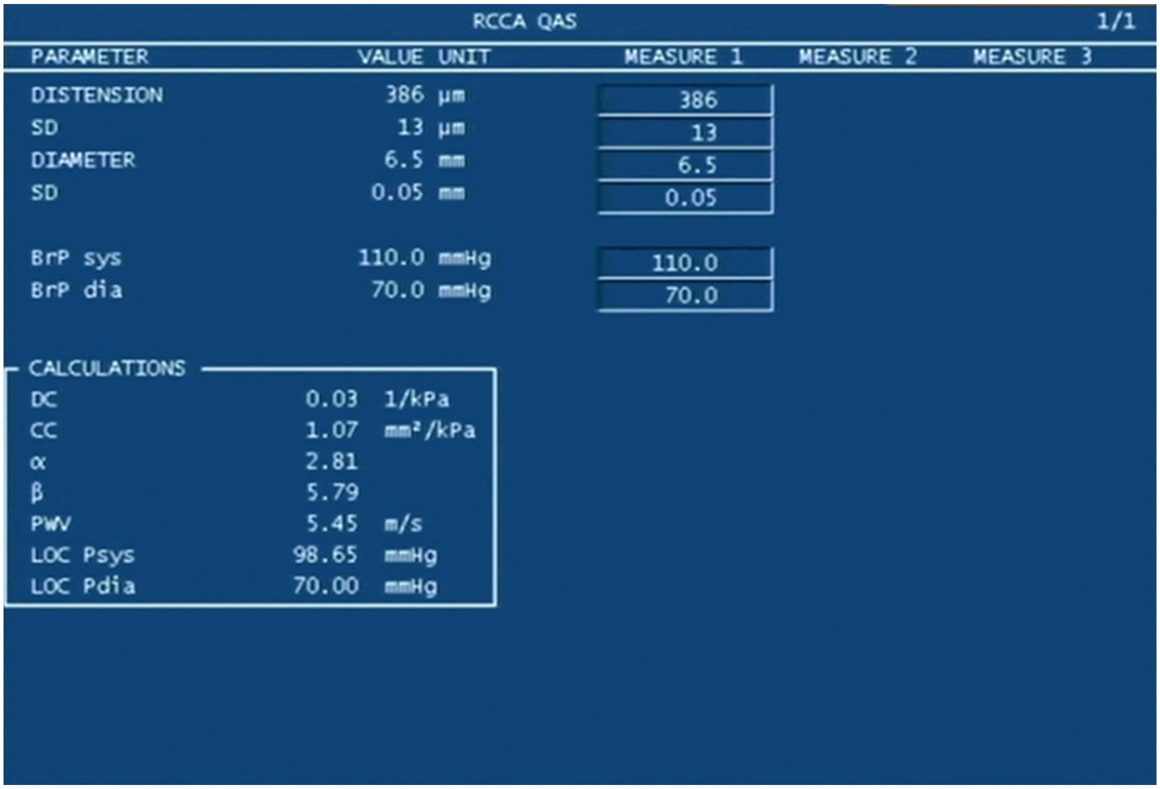


Figure 2. Elasticity related parameters (CC and β) of right CCA.

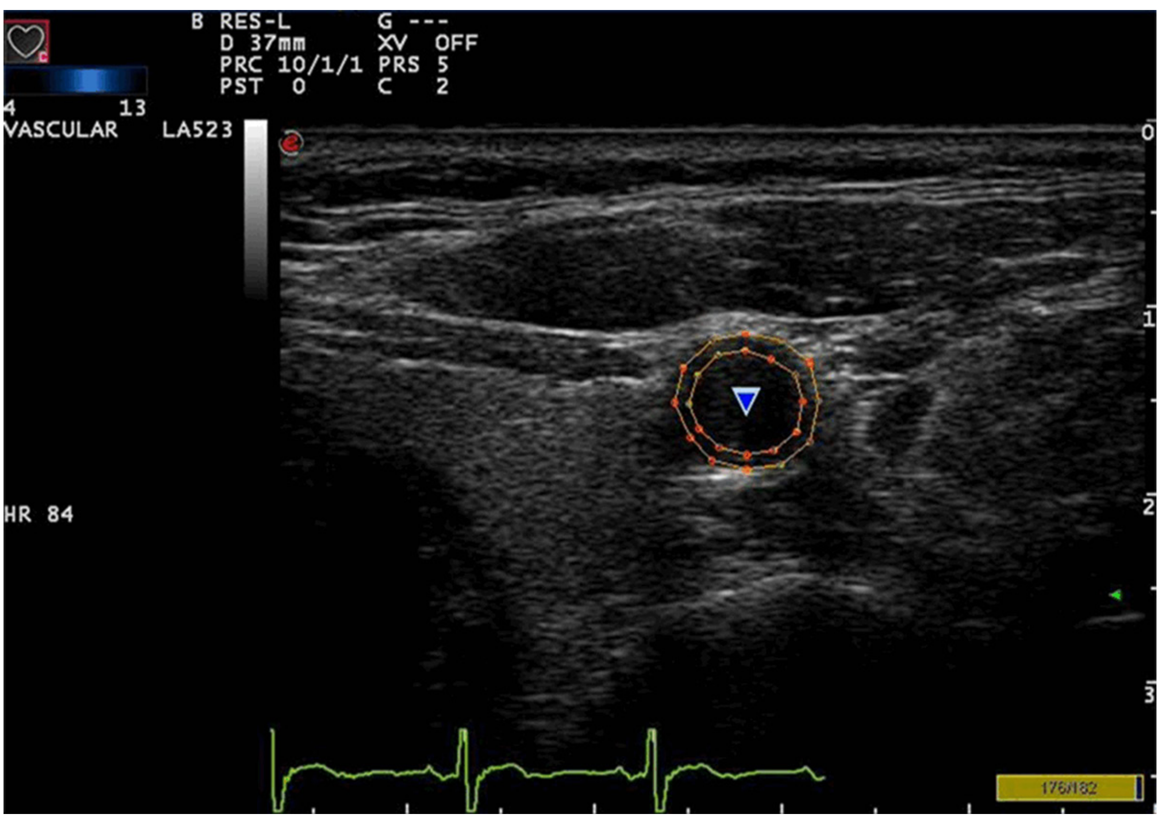


Figure 3. Semi-automatic tracing method was used. Twelve spots were marked on the intima of CCA which was divided into 12 segments. The reference spot was marked at the lumen center.

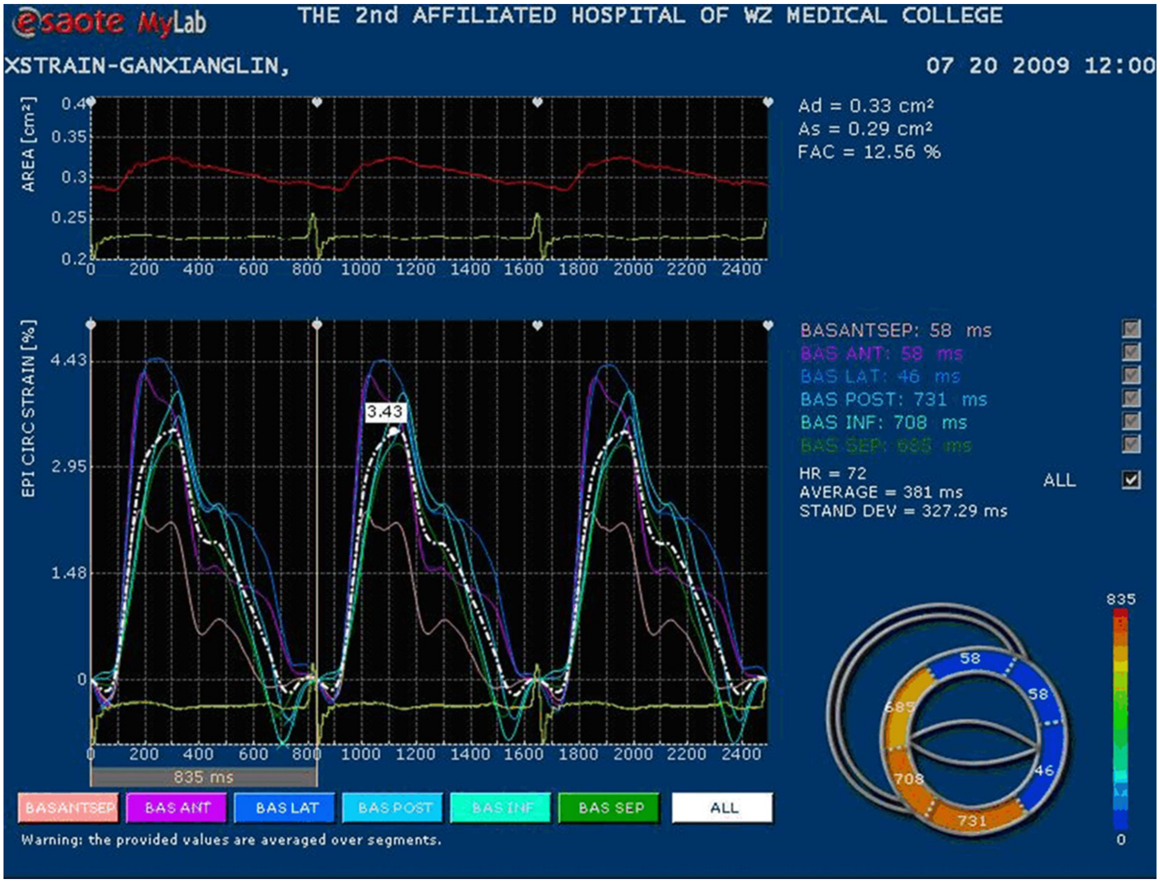


Figure 4. Automatic analysis with the supporting software of the ultrasound scanner. The mean CSmax was obtained from each segment. (CSmax=3.43).

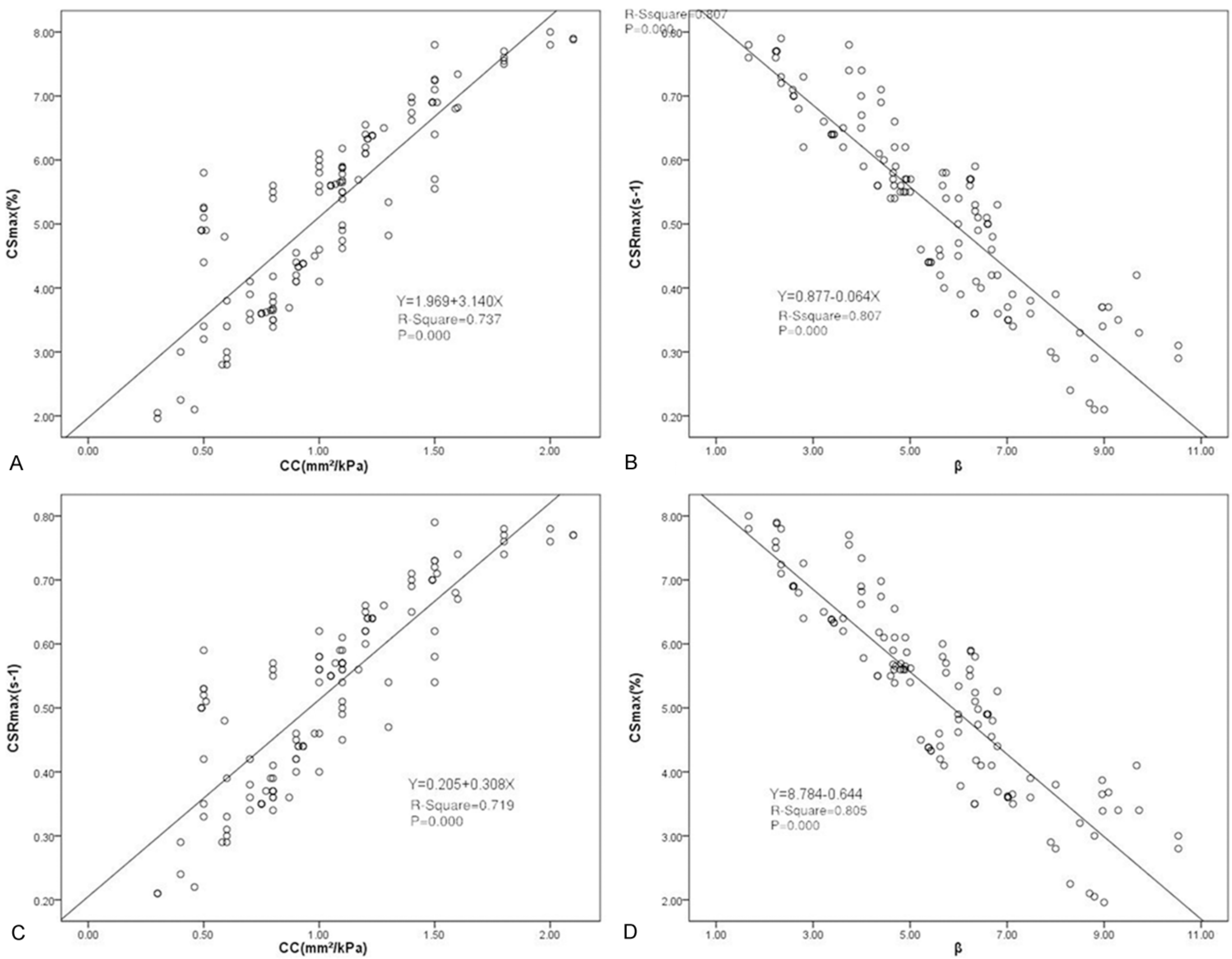
Table 2. Strain and elasticity related parameters in DN patients and healthy subjects

Group	n	CSmax (%)	CSRmax (s^{-1})	CC (mm^2/kPa)	β
Control	54	6.50±0.99	0.65±0.08	1.35±0.31	3.72±1.01
DN	68	4.19±0.78*	0.42±0.10*	0.78±0.26*	7.00±1.36*
F		2.368	2.273	3.009	2.971
t		14.075	14.230	10.867	14.791
P		0.000	0.000	0.000	0.000

Note: CSmax: maximum of Circumferential Strain; CSRmax: maximum of Circumferential Strain Rate; CC: Compliance Coefficient; β: stiffness index. *P<0.05 when compared with Control group.

was 1.4-1.5 cm and the location and height of sampling frame were adjusted. Then, the probe was fixed, and patients were asked to hold the breath. When 6 vascular dilations with favorable stability were present and observed (the standard deviation ≤15), the image was frozen and data were input to acquire the elasticity related parameters such as CC and β (**Figures 1** and **2**).

Measurement of stain related parameters of right CCA: The transverse section of CCA was obtained at 5 cm above the beginning part of CCA, and the probe was vertical to the skin. The intima was clearly indicated, and images of the transverse section of CCA were captured in 3 consecutive cardiac cycle. The videos were replayed, and the automatic analysis software was used to detect the strain related parameters. The image was fixed when the T wave was present in the EEG, and semi-automatic tracing method was used. Twelve spots were marked on the intima of CCA which was divided into 12 segments. The reference spot was localized at the lumen center, and automatic analysis was performed. The mean maximum of circumferential strain (CSmax) of different segments and the mean maximum of circumferential strain rate (CSRmax) of differ-



A
CSmax(%)
CC(mm²/kPa)
Y=1.969+3.140X
R-Square=0.737
P=0.000
B
CSRmax(s-1)
β
Y=0.877-0.064X
R-Ssquare=0.807
P=0.000
C
CSRmax(s-1)
CC(mm²/kPa)
Y=0.205+0.308X
R-Square=0.719
P=0.000
D
CSmax(%)
β
Y=8.784-0.644
R-Square=0.805
P=0.000

Figure 5. Correlation analysis of CSmax and CC (A), CSmax and β (B), CSRmax and CC (C) and CSRmax and β (D) of CCA in 68 DN patients and 54 healthy controls.

ent segments were determined for further analysis (**Figures 3** and **4**).

Statistical analysis

Data are expressed as mean ± standard deviation. Statistical analysis was performed with SPSS version 18.0. Pearson correlation analysis was employed to evaluate the correlation between elasticity and strain of the CCA. A value of $P<0.05$ was considered statistically significant.

Results

Of 54 healthy subjects the CSmax was 6.50%±0.99%, the CSRmax was 0.65±0.08 s^{-1}, and the CC was 1.35±0.31 mm^2/kPa. Of 68 patients with DN, the CSmax was 4.19%±0.78%, the CSRmax was 0.42±0.10 s^{-1} and CC was 0.78±0.26 mm^2/kPa. The CSmax, CSRmax and CCin healthy controls were significantly higher than those in DN groups (P=0.000). The β was 3.72±1.01 in 54 healthy controls and 7.00±1.36 in 68 patients with DM, showing markedly difference between them (P=0.000) (**Table 2**).

In healthy controls and DN patients, the correlation between elasticity and strain of the CCA was further evaluated. Results showed significant linear correlation between CSmax and CC, between CSmax and β, between CSRmax and CC and between CSRmax and β. The correlation coefficient between CSmax and CC was 0.859 (P=0.000), and the regression equation was Y=1.969+3.140X. The correlation coefficient between CSmax and β was -0.898 (P=0.000), and the regression equation was Y=9.794-0.644X. The correlation coefficient between CSRmax and CC was 0.848 (P=0.000), and the regression equation was Y=0.205+0.308X. The correlation coefficient between CSRmax and β was -0.898 (P=0.000), and the regression equation was Y=0.877-0.064X (**Figure 5**).

Discussion

Studies have revealed that atherosclerosis is closely related to the cardiovascular events [11]. Atherosclerosis is one of chronic complications of diabetes mellitus (DM) and significantly affects the quality of life of patients [12-15]. Thus, some investigators attempt to employ some tools to evaluate the arterial changes in early stage of atherosclerosis, which is helpful for the early diagnosis of atherosclerosis [16, 17]. Increasing studies focus on the elasticity of CCA of DN patients [18]. In recent years, vascular echo-tracking technology has been widely applied in the clinical evaluation of elasticity of the CCA, and plays an important role in this field [19-21]. It may monitor the changes in arterial diameter and blood pressure to automatically acquire the arterial compliance and stiffness related parameters. Elasticity related parameters can reflect the compliance of arterial wall after the heart pumps the blood, which is also known as the arterial elasticity [22]. These parameters may be acquired via the supporting software of the instrument. However, strain and strain rate are hot topics in recent years in the field of cardiology, and mainly used to evaluate the myocardial movement because the myocardial mechanics are closely related to the mechanics of arterial wall. Thus, some investigators attempt to use strain and strain rate to evaluate the movement of arterial wall and they confirm it is feasible [23, 24]. CSmax and CSR may reflect the deformability of the arterial wall in the circumferential direction and can be acquired via the supporting software of an instrument. This technology employs the space phase of ultrasound pixels, speckle tracking and boundary tracking, and the parameters such as velocity and strain of tissue movement are calculated [25]. Our results showed the CSmax, CSRmax and CC in DN patients were significantly lower than in healthy controls, but β in DN patients was markedly higher than in healthy controls [26, 27]. Correlation analysis in DN patients and healthy controls showed CSmax and CSRmax were positively related to CC, but negatively to β. That is, the CC increases and β reduces with the increases in CSmax and CSRmax, and vice versa. This implies that the better the deformation capability of CCA, the better its compliance is and the lower its stiffness is; on the contrary, the poorer the deformation capability of CCA, the poorer its compliance and the higher its stiffness is. In the presence of atherosclerosis, smooth muscle cell hyperplasia is present in the intima, extracellular matrix including collagen and proteoglycans accumulate and intimal hyperplasia causes the formation of connective tissues. However, the elasticity and deformation capability of connective tissues are lower than those of smooth muscle cells, and thus the elasticity and strain of arterial wall reduce [28].

Taken together, the elasticity and strain related parameters of CCA may reflect the mechanical characteristics of arteries and there is a significant correlation between them in patients with DN. Elasticity related parameters are classic indicators used to evaluate the mechanical movement, and strain and strain rate provide new indicators for the evaluation of mechanical movement of arteries. In our study, correlation analysis demonstrates the correlation between elasticity and stain of CCA in DN patients and healthy population. Our findings provide evidence for future investigations on the mechanisms underlying the movement of middle to large arteries in different populations, and broaden the exploration.

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Disclosure of conflict of interest

None.

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References

[1] van Bussel BC, Henry RM, Schalkwijk CG, Dekker JM, Nijpels G and Stehouwer CD. Low-grade inflammation, but not endothelial dysfunction, is associated with greater carotid stiffness in the elderly: the Hoorn Study. J Hypertens 2012; 30: 744-752.

[2] Shirai K, Utino J, Otsuka K and Takata M. A novel blood pressure-independent arterial wall stiffness parameter; cardio-ankle vascular index (CAVI). J Atheroscler Thromb 2006; 13: 101-107.

[3] Pahkala K, Hietalampi H, Laitinen TT, Viikari JS, Ronnemaa T, Niinikoski H, Lagstrom H, Talvia S, Jula A, Heinonen OJ, Juonala M, Simell O and Raitakari OT. Ideal cardiovascular health in adolescence: effect of lifestyle intervention and association with vascular intima-media thickness and elasticity (the Special Turku Coronary Risk Factor Intervention Project for Children [STRIP] study). Circulation 2013; 127: 2088-2096.

[4] Wang MC, Wu AB, Cheng MF, Chen JY, Ho CS and Tsai WC. Association of arterial stiffness indexes, determined from digital volume pulse measurement and cardiovascular risk factors in chronic kidney disease. Am J Hypertens 2011; 24: 544-549.

[5] Zahnd G, Orkisz M, Serusclat A, Moulin P and Vray D. Evaluation of a Kalman-based block matching method to assess the bi-dimensional motion of the carotid artery wall in B-mode ultrasound sequences. Med Image Anal 2013; 17: 573-585.

[6] Akasaka K, Takai R, Saito E, Kino S, Ito Y, Hasebe N and Sasajima T. Investigation of atherosclerosis using carotid ultrasonography. Rinsho Byori 2010; 58: 809-815.

[7] Duprez DA and Cohn JN. Arterial stiffness as a risk factor for coronary atherosclerosis. Curr Atheroscler Rep 2007; 9: 139-144.

[8] Zou C, Jiao Y, Zheng C, Zhao Y and Li X. Strain-blood pressure index for evaluation of early changes in elasticity of anterior tibial artery in patients with type 2 diabetes mellitus. Med Sci Monit 2014; 20: 2414-2420.

[9] Tervaert TW, Mooyaart AL, Amann K, Cohen AH, Cook HT, Drachenberg CB, Ferrario F, Fogo AB, Haas M, de Heer E, Joh K, Noel LH, Radhakrishnan J, Seshan SV, Bajema IM and Bruijn JA. Pathologic classification of diabetic nephropathy. J Am Soc Nephrol 2010; 21: 556-563.

[10] Popovic ZB, Benejam C, Bian J, Mal N, Drinko J, Lee K, Forudi F, Reeg R, Greenberg NL, Thomas JD and Penn MS. Speckle-tracking echocardiography correctly identifies segmental left ventricular dysfunction induced by scarring in a rat model of myocardial infarction. Am J Physiol Heart Circ Physiol 2007; 292: H2809-2816.

[11] O'Leary DH, Polak JF, Kronmal RA, Manolio TA, Burke GL and Wolfson SK Jr. Carotid-artery intima and media thickness as a risk factor for myocardial infarction and stroke in older adults. Cardiovascular Health Study Collaborative Research Group. N Engl J Med 1999; 340: 14-22.

[12] Yamagishi S. Diabetic macrovascular complications. Nihon Rinsho 2015; 73: 479-483.

[13] Xu RS. Pathogenesis of diabetic cerebral vascular disease complication. World J Diabetes 2015; 6: 54-66.
[14] Kumpatla S, Kothandan H, Tharkar S and Viswanathan V. The costs of treating long-term diabetic complications in a developing country: a study from India. J Assoc Physicians India 2013; 61: 102-109.
[15] El-Shal AS, Zidan HE and Rashad NM. Adiponectin gene polymorphisms in Egyptian type 2 diabetes mellitus patients with and without diabetic nephropathy. Mol Biol Rep 2014; 41: 2287-2298.
[16] Nurizal A, Antono D, Wijaya IP and Shatri H. Correlation between high-sensitivity C reactive protein and local arterial stiffness measured by radio frequency echotracking system in type 2 diabetic patients. Acta Med Indones 2014; 46: 308-313.
[17] Lim LS, Ling LH, Cheung CM, Ong PG, Gong L, Tai ES, Mathur R, Wong D, Foulds W and Wong TY. Relationship of systemic endothelial function and peripheral arterial stiffness with diabetic retinopathy. Br J Ophthalmol 2015; 99: 837-841.
[18] Rogowicz-Frontczak A, Araszkiewicz A, Pilacinski S, Zozulinska-Ziolkiewicz D, Wykretowicz A and Wierusz-Wysocka B. Carotid intima-media thickness and arterial stiffness in type 1 diabetic patients with and without microangiopathy. Arch Med Sci 2012; 8: 484-490.
[19] Yang S, Wang DZ, Zhang HX, He W and Chen BX. Echo-tracking technology assessment of carotid artery stiffness in patients with coronary slow flow. Ultrasound Med Biol 2015; 41: 72-76.
[20] Qiang Y, Ruijun G, Zhen C, Zhian L, Changyan L, Xiaohui Y, Shu L, Jie L, Yuanfeng M, Ruobing Z, Yan C, Qiao M, Shuang Z and Zhu Y. Evaluation of the impact of passive smoke on arterial elasticity via echo-tracking technology in a rabbit model. J Ultrasound Med 2014; 33: 1949-1956.
[21] Varady E, Feher E, Marko L and Battyany I. Determination of normal beta values via radio frequency echo-tracking technique in a healthy Central European population. Clin Hemorheol Microcirc 2014; 57: 185-189.
[22] Saito M, Okayama H, Inoue K, Yoshii T, Hiasa G, Sumimoto T, Nishimura K, Ogimoto A and Higaki J. Carotid arterial circumferential strain by two-dimensional speckle tracking: a novel parameter of arterial elasticity. Hypertens Res 2012; 35: 897-902.
[23] Rosen BD and Lima JA. The prognostic value of global circumferential strain in patients with suspected myocardial disease. JACC Cardiovasc Imaging 2015; 8: 550-552.
[24] Ryan TD, Jefferies JL, Chin C, Sticka JJ, Taylor MD, Harris R, Moore J, Goodridge E, Mount L, Bolyard AA, Otto B, Jones A, Shimamura A, Davies S and Myers K. Abnormal circumferential strain measured by echocardiography is present in patients with Shwachman-Diamond syndrome despite normal shortening fraction. Pediatr Blood Cancer 2015; 62: 1228-1231.
[25] Liszka J, Haberka M, Tabor Z, Finik M and Gasior Z. Two-dimensional speckle-tracking echocardiography assessment of left ventricular remodeling in patients after myocardial infarction and primary reperfusion. Arch Med Sci 2014; 10: 1091-1100.
[26] Ghadirpour A, Tarzamni MK, Naghavi-Behzad M, Abedi-Azar S, Koushavar H and Nezami N. Renal vascular Doppler ultrasonographic indices and carotid artery intima-media thickness in diabetic nephropathy. Med Ultrason 2014; 16: 95-99.
[27] Gepner AD, Korcarz CE, Colangelo LA, Hom EK, Tattersall MC, Astor BC, Kaufman JD, Liu K and Stein JH. Longitudinal effects of a decade of aging on carotid artery stiffness: the multiethnic study of atherosclerosis. Stroke 2014; 45: 48-53.
[28] Osidak MS, Osidak EO, Akhmanova MA, Domogatsky SP and Domogatskaya AS. Fibrillar, fibril-associated and basement membrane collagens of the arterial wall: architecture, elasticity and remodeling under stress. Curr Pharm Des 2015; 21: 1124-1133.