Quantification of Pulse Wave Velocity of Aorta of Diabetic Patients with Phase Contrast Magnetic Resonance ...

郭庭榮、溫志湧 ; 楊安石

E-mail: 9609688@mail.dyu.edu.tw

ABSTRACT

This thesis consists of two parts. Part I of this thesis is “ Quantification of pulse wave velocity of aorta of diabetic patients with phase contrast magnetic resonance imaging. ” Part II is ”In-vitro study of aortic wall shear stress with phase contrast magnetic resonance imaging. ” In Part I, Compliance of the aorta is an important factor of heart load and a clinically predictor of long-term prognosis in patients with diabetes mellitus and hypertension. Pulse wave velocity (PWV) of aortic blood flow is considered a surrogate for aortic compliance. In this study, a new, noninvasive method to estimate PWV based on the wave theory in gasdynamics were developed, in which spatial and temporal profiles of axial velocity along the thoracic aorta were analyzed. Phase contrast MRI (PC-MRI) were used to obtain the aortic geometry and flow information in the sagittal plane. Healthy volunteers and diabetic patients were studied and compared. Correlation studies were conducted with statistics. Furthermore, aortic compliance were derived from PWV. It is show that the PWV and aortic compliance for health volunteers were 6.49±1.49 m/s and 6.58 m3s2/kg respectively. On the other hand, the PWV and aortic compliance were 12.76±0.66 m/s and 1.57 m3s2/kg respectively, for diabetic patients, The PWV of diabetic patients are much higher than that of health volunteers. The aortic compliance of diabetic patients is worse than that of health volunteers. A clinically useful index to assess cardio-vascular risk is established. In Part II, wall shear stress is an important prediction of the cardiovascular disease. In this study, we used MRI to obtains the velocity distribution along the aortic model under simulated the heart circulation condition, and observed the influences of wall shear stresses on the aortic model. The experiments were divided into three parts: (1) A circular pipe flow experiment; (2)Steady in-vitro experiment on aortic model; (3) Unsteady in-vitro experiment on aortic model. In the circular pipe flow experiment, we true to validate the vessel-wall searching method based on “ no slip boundary condition ” of the fluid mechanics. The preliminary result is promising. In the steady and unsteady in-vitro experiments on aortic model, the newly developed vessel-wall searching method was adopted to determine the correct wall positions and wall shear stresses. The research demonstrated that on the inner wall surface around the aortic arch, the wall shear stress has changed significantly; It similar situation happens on outer wall surface along the descending aorta . The results are consistent with the early investigations in many literatures.

Keywords : Compliance ; Pulse Wave Velocity ; Phase Contrast MRI ; Diabetes ; Aorta ; Wall Shear Stress ; Aortic arch ; No Slip Boundary Condition

Table of Contents

REFERENCES

Part I [1] 國民健康局網站: http://www.bhp.doh.gov.tw/BHP/index.jsp ,民國93年4月。

[2] 行政院衛生署網站: http://www.doh.gov.tw/statistic/index.htm , 民國94年。

[3] Cruickshank K, Riste L, Anderson SG, Wright JS, Dunn G, Gosling RG. Aortic pulse-wave velocity and its relationship to mortality in diabetes and glucose intolerance: an integrated index of vascular function? Circulation 2002; 106(16):2085-2090.

[4] Stergiopulos N, Segers P, Westerhof N. Use of pulse pressure method for estimating total arterial compliance in vivo. Am J Physiol 1999; 276:H424-H428.

[5] Bogren HG, Mohiaddin RH, Klipstein RK,Firmin DN, Undrwood RS, Rees SR, Longmore DB. The function of the aorta in ischemic heart disease: a magnetic resonance and angiographic study of aortic compliance and blood flow patterns. Am Heart J 1989; 118:234-247.

[6] Groenink M, de Roos A, Mulder BJ, Spaan JA, van der Wall EE. Changes in aortic distensibility and pulse wave velocity assessed with magnetic resonance imaging following beta-blocker therapy in the Marfan syndrome. Am J Cardiol 1998; 82:203-208.

[7] Heintz B, Gillessen T, Walkenhorst F., vom Dahl J, Dorr R, Krebs W, Hanrath P, Sieberth HG. Evaluation of segmental elastic properties of the aorta in normotensive and medically treated hypertensive patients by intravascular ultrasound [erratum published in J Hypertens 1993; 11:following H71]. J Hypertens 1993; 11:1253-1258.

[8] Honda T, Yano K, Matsuoka H, Hamada M, Hiwada K. Evalu- ation of aortic distensibility in patients with essential hypertension by using cine magnetic resonance imaging. Angiology 1994; 45:207-212.

[9] Mohiaddin RH, Firmin DN, Longmore DB. Age-related changes of human aortic flow wave velocity measured noninvasively by magnetic resonance imaging. J Appl Physiol 1993;74:492-497.

[10] Resnick LM, Militianu D, Cunnings AJ, Pipe JG, Evelhoch JL, Soulen RL. Direct magnetic resonance determination of aortic distensibility in essential hypertension: relation to age, abdominal visceral fat, and in situ intracellular free magnesium. Hypertension 1997; 30:654-659.

[11] Franklin SS, Khan SA, Wong ND, Larson MG, Levy D. Is pulse pressure useful in predicting risk of coronary heart disease? The Framingham heart study. Circulation 1999; 100:354-360.

[12] The American Diabetes Association:Report of Expert Committer on the diagnosis and Classification of diabetes mellitus.Diabetes Care 1997;20:1183-1197.

[13] Cameron JD, Bulpitt CJ, Pinto ES, Rajkumar C. The aging of elastic and muscular arteries: a. comparison of diabetic and non-diabetic subjects. Diabetes Care 2003; 26: 2133-8.

[14] Ohnishi H, Saitoh S, Takagi S, Ohata J, Isobe T, Kikuchi Y, Takeuchi H, Shimamoto K. Pulse wave velocity as an indicator of atherosclerosis in impaired fasting glucose: the Tanno and Sobetsu study. Diabetes Care, February 1, 2003; 26(2): 437-440.

[15] Tsuchiya M, Suzuki E, Egawa K, Nishio Y, Maegawa H, Morikawa S, InubushiT, Kashiwagi A. Abnormal peripheral circulation in type 2 diabetic patients with normal ankle-brachial index associates with coronary atherosclerosis, large artery stiffness, and peripheral vascular resistance. Diabetes Research and Clinical Practice 70 (2005) 253-262 [16] Liu ZR, Ting CT, Zhu SX, Yin FC. Aortic compliance in human hypertension. Hypertension 1989;100:354-360.

[17] Stefanadis C, Stratos C, Vlachopoulos C, Marakas S, Boudoulas H, Kallikazaros I, Tsiamis E, Toutouzas K, Sioros L, Toutouzas P. Pressure-diameter relation of the human aorta. A new method of determination by the application of a special ultrasonic dimension catheter. Circulation 1995;92:2210-2219.

[18] Vulliemoz S, Stergiopulos N, Meuli R. Diagnostic and Inter- ventional Radiology Department, CHUV, Lausanne, Switzerland. Estimation of local aortic elastic properties with MRI Magn. Reson Med. 2002;47:649-654.

[19] Laffon E, Marthan R, Montaudon M, Latrabe V, Laurent F, Ducassou D. Feasibility of aortic pulse pressure and pressure wave velocity with MRI measurement in young adults. J Magn Reson Imaging 2005;21(1):53-58.

[20] Boese JM, Bock M, Schoenberg SO, Schad LR. Estimation of aortic compliance using magnetic resonance pulse wave velocity measurement. Phys. Med. Biol. 2000;45(6):1703-1713.

[21] Danias PG, Tritos NA, Stuber M, Botnar RM, Kissinger KV, Manning WJ. Comparison of aortic elasticity determined by cardiovascular magnetic resonance imaging in obese versus lean adults. Am J Cardiol 2003;91(2):195-199.

[22] Yu, H.Y., Peng, H.Y., Wang, J.L., Wen, C.Y., and Tseng, W.Y., “ Quantification of the Pulse Wave Velocity of the Descending Aorta Using Axial Velocity Profiles from Phase-Contrast Magnetic Resonance Imaging, ” Magnetic Resonance in Medicine, Vol. 56, pp 876-883, 2006.

[23] Anderson, Jr. JD. Modern Compressible Flow, 2nd ed., McGraw Hill, 2000.

[24] Yu, H. Y., Pung, H. S., Wen, C. Y., Wang, J. L. and Tseng, W. Y., “ DirectVisualization of Pulse Wave Velocity of Aorta by Phase Image of Cine-MRI, ” Proceedings of ISMRM 11th annual meeting, 5/13, Toroto, Canada, 2003.

[25] Lankhaar, J. W., Hofman, M. B. M., Mrcus, J. T., Zwanenburg, J. J. M., Faes, T. J. C., Noordegraaf, A. V., “ Correction of Phase Offset Errors in Main Pulmonary Artery Flow Quantification. ” Journal of Magnetic Resonance Imaging. 22:73-79, 2005.

[26] Rogers W.J, Hu Y.L., Coast D., Vido D.A., Kramer C.M., Pyeritz R.E. and Reichek N., Age-associated changes in regional aortic pulse wave velocity. J Am Coll Cardiol 38 (2001), pp. 1123 – 1129.

[27] Tsuchiya M, Suzuki E, Egawa K, Nishio Y, Maegawa H, Morikawa S, Inubushi T, Kashiwagi ,.Abnormal peripheral circul- ation in type 2 diabetic patients with normal ankle-brachial index associates with coronary atherosclerosis,large artery stiffness,and peripheral vascular resistance. Diabetes Res Clin Pract,2005,70(3), 253-262.
[28] Ohnishi H., Saitoh S., Takagi S., Ohata J.-I., Isobe T., Kikuchi Y., Takeuchi H., Shimamoto K. , Pulse wave velocity as an indicator of atherosclerosis in impaired fasting glucose:the Tanno and Sobetsu study[J].Diabetes-Care, 2003,26(2):437-440.
[29] Yamashina A, Tomiyama H, Takeda K, Tsuda H, Arai T, Hirose K, Koji Y, Hori S, Yamamoto Y. ,Validity,reproducibility and clinical significance of non-invasive brachial-ankle pulse wave velocity measurement.Hypertens Res,2002,25:359-364 PartII [1] 行政院衛生署網站: http://www.doh.gov.tw/statistic/index.htm ,民國94年。
[2] Sahs, A L.,“ Observations on the Pathology of Saccular Aneur- ysms. ” J. Neurosurg. 24:79-806, 1996.
[3] Anderson CM, Turski PA, Edelman RR. Flow quantification. In: Anderson CM, Edelman RR, Turski PA, eds. Clinical magnetic resonance angiography. New York: Raven, 1993:127 -128 [4] Taxon M. Hemodynamic basis of atherosclerosis with critique of the cholesterol-heart disease hypothesis . Wallingford, U.K.: Begell House, 1995 :48 – 49 [5] Oyre S, Ringgard S, Erlandsen M, et al. Automatic Accurate In Vivo Determinations of Blood Flow, Wall Shear Stress and Subpixel Vessel Wall Position in the Common Carotid Artery Throughout the Entire Heart Cycle by MRI (abstract). In 70th Scientific Sessions of the American Heart Association; 1997 Nov 10-14; Orlando, USA Circulation. 1997; 96 (8 Suppl): I-50.
[6] Grigioni M, Marano G, Formigari R, et al. Wall shear stress swing and the development of intimal hyperplasia in rabbit carotid artery (abstract). In Proceedings of the XXV European Society for Artificial Organs ESAO Congress, 1998 Nov 1113; Bologna, Italy. Int J Artif Organs. 1998; 21: 619.
[7] Liepsch D, Pflugbeil G, Matsuo T, et al. Flow visualization and 1and 3D laserDoppleranemometer measurements in models of human carotid arterie. Clin Hemorheol Microcirc. 1998; 18: 130.
[8] Oyre S., Pedersen E. M., Ringgaard S., Boesiger P. and Paaske W. P., In vivo Wall Shear Stress Measured by Magnetic Resonance Velocity Mapping in the Normal Abdominal Aorta. Eur J Vasc Endovasc Surg 13, 263-271,1997 [9] James E. Moore Jr., Chengpei Xu, Seymour Glagov, Christopher K. Zarins, David N. Ku. Fluid wall shear stress measurements in a model of the human abdominal aorta: oscillatory behavior and relationship to atherosclerosis. Atherosclerosis 110, 225-240,1994 [10] Gnasso A, Carallo C, Irace C, Spagnuolo V, De Novara G, Mattioli PL, Pujia A. Association between intima-media thickness and wall shear stress in the common carotid arteries in healthy male subjects. Circulation. 1996;94:3257 – 3262.
[11] Zhao S.Z., Xu X.Y., Hughes A.D., Thom S.A., Stanton A.V., Ariff B.,Long Q., Blood flow and vessel mechanics in a physiologically realistic model of a human carotid arterial bifurcation, Journal of Biomechanics, Vol:33, 975-984,2000 [12] 朱偉光，人體主動脈剪力分佈之數值模擬與分析，私立中華大學機械與航太研究所碩士論文，民國九十一年。
[13] Uwe Kohler, Ian Marshall, Malcolm B. Robertson, Quan Long, X. Yun Xu, and Peter R. Hoskins, MRI Measurement of Wall Shear Stress Vectorsin Bifurcation Models and Comparison With CFD Predictions. Journal of Magnetic Resonance Imaging, Vol:14, 563-573,2001 [14] Klanchar, M., Tarbell, J.M. and Wang, D.M., 1990. In vitro study of the influence of radial wall motion on wall shear stress in an elastic tube model of the aorta. Circulation Research ,Vol. 66, pp. 1624 – 1635.
[15] Zhaoa, S. Z., Ariffb, B., Longa, Q., Hughesb, A. D., Thomb, S. A., Stantonb, A. V., Xua, X. Y.,“ Inter-individual Variations in Wall Shear Stress and Mechanical Stress Distributions at the Carotid Artery Bifurcation of Healthy Humans. ” Journal of Biomechanics. 35:1367 – 1377, 2002.
[16] Marshalla, I., Zhaob, S., Papathanasopouloua, P., Hoskinsa, P., Xub, X. Y.,“ MRI and CFD Studies of Pulsatile Flow in Healthy and Stenosed Carotid Bifurcation Models. ” Journal of Biomechanics. 37:679 – 687, 2004.
[17] Hugo G., Bogren, MD and Michael H. Buonocore, MD,4D Magnetic Resonance Velocity Mapping of Blood Flow Patterns in the Aorta in Young vs. Elderly Normal Subjects. Journal of Magnetic Resonance Imaging, Vol:10, 861-869,1999 [18] Hugo G., Bogren, MD, Richard H. Klipstein, MB, PhD, David N. Firmin, BSc, Mphil, Raad H. Mohiaddin, MB, MSc, S. Richard Underwood, DM, MRCP, R. Simon O Rees, FRCP, FRCR, and Donald B. Longmore, FRCS. London, England, American Heart Journal, vol. 117, no. 6, pp.1214-1222,1989 [19] 廖大煜，利用連續磁振造影及壓力換能器發展一套左心腔室之體積與壓力量測系統，國立臺灣大學醫學工程學研究所碩士論文，民國九十一年。
[20] 莊家銘，二維圖樣特徵偵測-以磁振左心室影像及其特徵搜尋為案例，私立大葉大學工業工程學系碩士論文，民國九十年。
[21] 陳文哲，二維影像輪廓自適性分割與三維影像流向重建—以磁振肝門靜脈影像處理為案例，私立大葉大學工業工程學系碩士論文，民國九十一年。
[22] Oyre, Sten; Ringgaard, Steffen; Kozerke, Sebastian; Paaske, William P.; Erlandsen, Mogens;. Accurate noninvasive quantitation of blood flow, cross-sectional lumen vessel area and wall shear stress by three-dimensional paraboloid modeling of magnetic resonance imaging velocity data. Journal of the American College of Cardiology. Vol: 32, Issue: 1, pp. 128-134, 1998 [23] 劉清吉，人體主動脈流場之特性研究，私立大葉大學機械與自動化工程學系碩士論文，民國九十三年。
[24] 蔡坤晃，主動脈剝離現象之流場分析，私立大葉大學機械與自動化工程學系碩士論文，民國九十四年。
[25] Francis, J. G. F.,“ The QR Transformation I, ” Comput. J., vol. 4:265-271, 1961.
[26] Nerem, R. M.,“ Vascular Fluid Mechanics, the Arterial Wall, and Atherosclerosis, ” J. Biomech. Eng., 114:274 – 282, 1992.

[27] Shahcheraghi, N., Dwyer, H. A., Cheer, A. Y., Barakat, A. I., Rutaganira, T.,“ Unsteady and Three-Dimensional Simulation of Blood Flow in the Human Aortic Arch, ” Journal of Biomechanical Engineering. Vol. 124, 378-387, 2002.
[28] Murray R. Spiegel，Vector Analysis，滄海書局，民國八十五年。
[29] Miller, G.E., Etter, B.D., and Dorsi, J., A Multiple Disk Centrifugal Pump as a Blood Flow Device, IEEE Transactions on Biomedical Engineering, vol. 37, no. 2, pp. 157-163, 1990.