경동맥 협착 수술 환자 모델에 대한 혈류 시뮬레이션 분석

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Patient-Specific Study of Post-CEA Models: Comparison of Primary Closure and Patch Angioplasty

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Abstract : Carotid endarterectomy is considered to be the 'golden standard' to relieve stenosis conditions in both symptomatic and asymptomatic patients. Despite of numerous surgical techniques being developed in past few decades, superiority of one over another is still controversial. In this study, we present patient-specific results using computational fluid dynamics(CFD) to provide unbiased quantitative analysis of both primary closure(PC) and patch angiography(PA). Hemodynamic properties are calculated based on actual patient conditions to obtain values closer to the reality. As a result, pressure and flow rate match measurements and literature. WSS-related indexes show favorable outcomes for PC than PA, and PC technique may provide better postoperative consequences compared to PA.

1. 서 론

Carotid endarterectomy(CEA) has been the golden rule for treatment of moderate to severe carotid artery stenosis.[1] Among various CEA techniques developed till date, two closing techniques are widely used, namely primary closure(PC) and patch angioplasty(PA), and superiority of these two techniques over one another is still undetermined. While numerous studies suggest negligible differences between two techniques[2-4], other studies show superiority of one method over another. either PA[5-7] or PC[8-10]. The main objective of this study is to clarify the differences in postoperative conditions of both PA and PC conducted by experienced physicians. Hemodynamic properties and WSS-related indexes are calculated to quantitatively and visually compare two distinct surgical procedures.

Table 1 Patient Specification

Type	Patient Model	Stenosis Location*
PC	001, 002, 003	R, R, R
PA	001, 002, 003	L, L, R

*R: Right, L: Left

2. 본 론

2.1. Patient-Specific Data

To quantify patient-specific carotid artery(CCA) flow rate, Ultrasound(US) data is obtained at proximal site of CCA. The site is chosen to minimize the turbulence effect generated from the carotid bifurcation, and maintain laminar flow measurement. Extracted US data is then digitized

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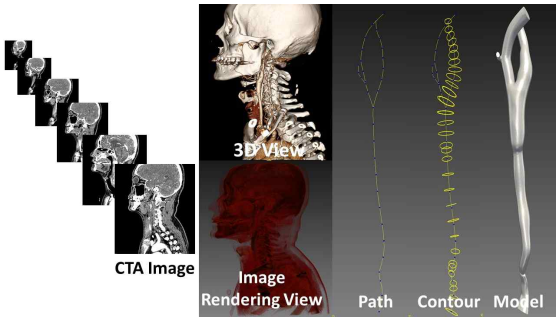

Fig. 1 Schematic of computational modelling process.

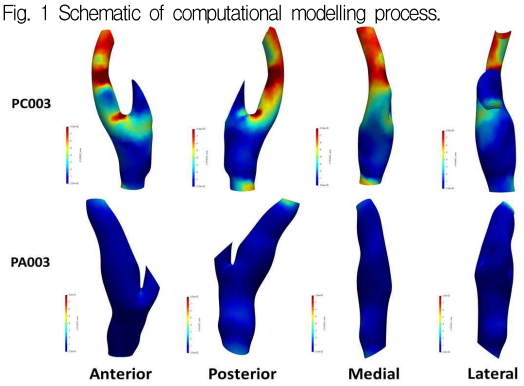

Fig. 2 Comparison of TAWSS between a PC and PA case. Note low TAWSS in PA case is an indicator for arteriosclerosis.

and smoothened with interpolation, and formatted as inflow rate to our simulations. Postoperative carotid CTA data is reconstructed as computational model using an open-source program SimVascular[11] as well. The schematic for model reconstruction is illustrated in Fig.1.

2.2. 모델 형상

Both PC and PA models were 3 cases each, so total of 6 patient data is acquired. Each models are constructed and smoothened to prevent error in computational simulation. Finer mesh is generated at bifurcation region to capture complex flow phenomena such as swirl and reversed flow. Each model has mesh quantity of about 0.4 to 0.7 million depending on their anatomical structures.

2.3. 수치 해석

Newtonian incompressible, and rigid vessel wall assumptions are applied which are typically used in simulation fields, especially to reduce computational costs. Mass conservation and Navier-Stokes equations are directly solved in discretized form in the program using 96 core(2.2 GHz) workstation for 2 days per simulation case. Time step is assigned as 0.001s with 7 cardiac cycles and run till convergence.

2.4. FSI 모델

Fluid-structure interaction model is utilized to simulate and quantify displacement of vessel models. Since use of PA material type is very controversial,[12] we assumed equal elastic modulus for both PC and PA cases. Blood density and viscosity are set to be ρ = 1.06 g/cm^3, μ = 0.04 g/cm·s, and 1 inlet, CCA, and 2 outlets, ICA and ECA are created. The outlet conditions are considered as 3-element Windkessel outlet boundaries, and their parameters are calculated with corresponding inflow and mean pressure conditions, where POD 4-5 brachial artery pressure data is utilized.

3. 결 론

The conclusions are as follows:

1) Pressure and flow rate distribution match given brachial artery pressure data and literature.
2) WSS-related indexes such as TAWSS and OSI are in favor of PC compared to PA.(Fig.2)
3) RRT range of PA case is broader and higher compared to PC cases, showing significant differences in postoperative states.
4) Overall results indicate more favorable outcome for PC cases. Therefore, PC may provide better postoperative consequences compared to PA.

참고 문헌

(1) Swain, S., Turner, C., Tyrrell, P. and Rudd, A.,

2008. "Diagnosis and initial management of acute stroke and transient ischaemic attack: summary of NICE guidance." Bmj, 337, p.786.

(2) Maertens, V., Maertens, H., Kint, M., Coucke, C. and Blomme, Y., 2016. "Complication rate after carotid endarterectomy comparing patch angioplasty and primary closure." Annals of vascular surgery, 30, pp.248-252.

(3) Galyfos, G., Geropapas, G. and Kerasidis, S., 2016. "Carotid Endarterectomy: Which Technique Prevails." Journal of Vascular & Endo Surgery, 1, p.1.

(4) Yun, W.S., Kim, D.I., Lee, K.B., Park, U.J., Kim, Y.W., Kim, G.M., Chung, C.S., Bang, O.Y. and Kim, K.H., 2010. "Comparison of Outcomes between Primary Closure vs. Patch Angioplasty in Carotid Endarterectomy." Journal of the Korean Surgical Society, 78(5), pp.314-319.

(5) Ho, K.J., Nguyen, L.L. and Menard, M.T., 2012. "Intermediate-term outcome of carotid endarterectomy with bovine pericardial patch closure compared with Dacron patch and primary closure." Journal of vascular surgery, 55(3), pp.708-714.

(6) MRC Asymptomatic Carotid Surgery Trial (ACST) Collaborative Group, 2004. "Prevention of disabling and fatal strokes by successful carotid endarterectomy in patients without recent neurological symptoms: randomised controlled trial." The Lancet, 363(9420), pp.1491-1502.

(7) European Carotid Surgery Trialists' Collaborative Group, 1998. "Randomised trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST)." The Lancet, 351(9113), pp.1379-1387.

(8) Avgerinos, E.D., Chaer, R.A., Naddaf, A., El-Shazly, O.M., Marone, L. and Makaroun, M.S., 2016. "Primary closure after carotid endarterectomy is not inferior to other closure techniques." Journal of vascular surgery, 64(3), pp.678-683.

(9) Chung, B.H., Heo, S.H., Park, Y.J., Kim, Y.W., Woo, S.Y. and Kim, D.I., 2019. "Comparative Analysis Using Propensity Score Matching Analysis: Primary Closure Versus Patch Angioplasty During Carotid Endarterectomy." Annals of vascular surgery.

(10) Yun, W.S., Kim, D.I., Lee, K.B., Park, U.J., Kim, Y.W., Kim, G.M., Chung, C.S., Bang, O.Y. and Kim, K.H., 2010. "Comparison of Outcomes between Primary Closure vs. Patch Angioplasty in Carotid Endarterectomy." Journal of the Korean Surgical Society, 78(5), pp.314-319.

(11) Updegrove, A., Wilson, N.M., Merkow, J., Lan, H., Marsden, A.L. and Shadden, S.C., 2017. "SimVascular: an open source pipeline for cardiovascular simulation." Annals of biomedical engineering, 45(3), pp.525-541.

(12) Bond, R., Rerkasem, K., Naylor, A.R., Aburahma, A.F. and Rothwell, P.M., 2004. "Systematic review of randomized controlled trials of patch angioplasty versus primary closure and different types of patch materials during carotid endarterectomy." Journal of vascular surgery, 40(6), pp.1126-1135.