zbMATH Open
THE FIRST RESOURCE FOR MATHEMATICS

Torii, Ryo; **Oshima, Marie**; **Kobayashi, Toshio**; **Takagi, Kiyoshi**; **Tezduyar, Tayfun E.**
Fluid-structure interaction modeling of a patient-specific cerebral aneurysm: influence of structural modeling. (English) Zbl 1169.74032
Comput. Mech. 43, No. 1, 151-159 (2008).

Summary: Fluid-structure interaction (FSI) simulations of a cerebral aneurysm with the linearly elastic and hyperelastic wall constitutive models are carried out to investigate the influence of the wall-structure model on patient-specific FSI simulations. The maximum displacement computed with the hyperelastic model is 36% smaller compared to the linearly elastic material model, but the displacement patterns such as the site of local maxima are not sensitive to the wall models. The blood near the apex of an aneurysm is likely to be stagnant, which causes very low wall shear stress and is a factor in rupture by degrading the aneurysmal wall. In this study, however, relatively high flow velocities due to the interaction between the blood flow and aneurysmal wall are seen to be independent of the wall model. The present results indicate that both linearly elastic and hyperelastic models can be useful to investigate aneurysm FSI.

MSC:

74L15 Biomechanical solid mechanics
74F10 Fluid-solid interactions (including aero- and hydro-elasticity, porosity, etc.)
74B05 Classical linear elasticity
74B20 Nonlinear elasticity
92C20 Neural biology

Cited in **52** Documents

Keywords:

maximum displacement; hyperelastic model; linearly elastic model

Full Text: DOI

References:

[1] Steiger HJ (1990) Pathophysiology of development and rupture of cerebral aneurysms. Acta Neurochir Suppl 48: 1–57

[2] Torii R, Oshima M, Kobayashi T, Takagi K, Tezduyar TE (2006) Fluid–structure interaction modeling of aneurysmal conditions with high and normal blood pressures. Comput Mech 38: 482–490 · Zbl 1160.76061 · doi:10.1007/s00466-006-0065-6

[3] Komatsu Y, Yasuda S, Shibata T, Ono Y, Hyodo A, Nose T (1994) Management for subarachnoid hemorrhage with negative initial angiography. Neurol Surg (in Japanese) 22: 43–49

[4] Taylor CL, Yuan Z, Selman WR, Ratcheson RA, Rimm AA (1995) Cerebral arterial aneurysm formation and rupture in 20,767 elderly patients: hypertension and other risk factors. J Neurosurg 83: 812–819· doi:10.3171/jns.1995.83.5.0812

[5] Torii R, Oshima M, Kobayashi T, Takagi K, Tezduyar TE (2007) Fluid–structure interaction modeling of blood flow and cerebral aneurysm: significance of arterial and aneurysm shape. In: Proceedings of USNCCM9, San Francisco, July · Zbl 1229.74101

[6] Fung YC (1993) Biomechanics: mechanicsl properties of living tissue, 2 edn. Springer, New York

[7] Humphrey JD (2002) Cardiovascular solid mechanics. Cells, tissues, and organs. Springer, New York

[8] Torii R, Oshima M, Kobayashi T, Takagi K, Tezduyar TE (2007) Influence of wall elasticity in patient-specific hemodynamic simulations. Comput Fluids 36: 160–168 · Zbl 1113.76105 · doi:10.1016/j.compfluid.2005.07.014

[9] Baek S, Gleason RL, Rajagopal KR, Humphrey JD (2007) Theory of small on large: Potential utility in computations of fluid–solid interactions in arteries. Comput Methods Appl Mech Eng 196: 2070–3078 · Zbl 1127.74026 · doi:10.1016/j.cma.2006.06.018

[10] Figueroa CA, Vignon-Clementel IE, Jansen KE, Hughes TJR, Taylor CA (2006) A coupled momentum method for modeling blood flow in three-dimensional deformable arteries. Comput Meth Appl Mech Eng 195: 5685–5706 · Zbl 1126.76029 · doi:10.1016/j.cma.2005.11.011

[11] Raghavan ML, Vorp DA (2000) Toward a biomechanical tool to evaluate rupture potential of abdominal aortic aneurysm: identification of a finite strain constitutive model and evaluation of its applicability. J Biomech 33(4): 475–482· doi:10.1016/S0021-9290(99)00201-8

[12] DI Martino ES, Vorp D (2003) Effect of variation in intraluminal thrombus constitutive properties on abdominal aortic aneurysm wall stress. Ann Biomed Eng 31: 804–809· doi:10.1114/1.1581880

© 2022 FIZ Karlsruhe GmbH

[13] Leung JH, Wright AR, Cheshire N, Crane J, Thom SA, Hughes AD, Xu Y (2006) Fluid structure interaction of patient specific abdominal aortic aneurysms: a comparison with solid stress models. Biomed Eng 5 (online)

[14] Bazilevs Y, Calo VM, Zhang Y, Hughes TJR (2006) Isogeometric fluid–structure interaction analysis with applications to arterial blood flow. Comput Mech 38: 310–322 · Zbl 1161.74020 · doi:10.1007/s00466-006-0084-3

[15] Tezduyar TE, Sathe S, Cragin T, Nanna B, Conklin BS, Pausewang J, Schwaab M (2007) Modeling of fluid–structure interactions with the space–time finite elements: Arterial fluid mechanics. Int J Numer Meth Fluids 54: 901–922 · Zbl 1276.76043 · doi:10.1002/fld.1443

[16] Tezduyar TE, Sathe S, Schwaab M, Conklin BS (2008) Arterial fluid mechanics modeling with the stabilized space–time fluid–structure interaction technique. Int J Numer Meth Fluids 57: 601–629. doi: 10.1002/fld.1633 · Zbl 1230.76054 · doi:10.1002/fld.1633

[17] Holzapfel GA, Gasser TC (2000) A new constitutive framework for arterial wall mechanics and a comparative study of material models. J Elast 61: 1–48 · Zbl 1023.74033 · doi:10.1023/A:1010835316564

[18] Humphrey JD, Na S (2002) Elastodynamics and arterial wall stress. Ann Biomed Eng 30: 509–523· doi:10.1114/1.1467676

[19] Gasser TC, Holzapfel GA (2007) Finite element modeling of balloon angioplasty by considering overstretch of remnant non-diseased tissues in lesions. Comput Mech 40: 47–60 · Zbl 1175.74055 · doi:10.1007/s00466-006-0081-6

[20] Hariton I, deBotton G, Gasser TC, Holzapfel GA (2005) How to incorporate collagen fibers orientations in an arterial bifurcation? In: Proceedings of 3rd IASTED international conference on biomechanics, Benidorm, Spain, September

[21] Williamson SD, Lam Y, Younis HF, Huang H, Patel S, Kaazempur-Mofrad MR, Kamm RD (2003) On the sensitivity of wall stresses in diseased arteries to variable material properties. J Biomech Eng 125: 147–155· doi:10.1115/1.1537736

[22] Karino T, Takeuchi S, Kobayashi N, Motomiya M, Mabuchi S (1993) Fluid dynamics of cerebrovascular disease (in Japanese). Neurosurgeons 12: 15–24

[23] Tezduyar TE (1992) Stabilized finite element formulations for incompressible flow computations. Adv Appl Mech 28: 1–44 · Zbl 0747.76069 · doi:10.1016/S0065-2156(08)70153-4

[24] Tezduyar TE, Behr M, Liou J (1992) A new strategy for finite element computations involving moving boundaries and interfaces – the deforming-spatial-domain/space–time procedure: I. The concept and the preliminary numerical tests. Comput Methods Appl Mech Eng 94(3): 339–351 · Zbl 0745.76044 · doi:10.1016/0045-7825(92)90059-S

[25] Tezduyar TE, Behr M, Mittal S, Liou J (1992) A new strategy for finite element computations involving moving boundaries and interfaces–the deforming-spatial-domain/space–time procedure: II. Computation of free-surface flows, two-liquid flows, and flows with drifting cylinders. Comput Methods Appl Mech Eng 94(3): 353–371 · Zbl 0745.76045 · doi:10.1016/0045-7825(92)90060-W

[26] Tezduyar TE (2003) Computation of moving boundaries and interfaces and stabilization parameters. Int J Numer Methods Fluids 43: 555–575 · Zbl 1032.76605 · doi:10.1002/fld.505

[27] Hughes TJR, Brooks AN (1979) A multi-dimensional upwind scheme with no crosswind diffusion. In: Hughes TJR (ed) Finite element methods for convection dominated flows, AMD, vol 34, ASME, New York, pp 19–35

[28] Brooks AN, Hughes TJR (1982) Streamline upwind/Petrov-Galerkin formulations for convection dominated flows with particular emphasis on the incompressible Navier–Stokes equations. Comput Methods Appl Mech Eng 32: 199–259 · Zbl 0497.76041 · doi:10.1016/0045-7825(82)90071-8

[29] Tezduyar TE, Mittal S, Ray SE, Shih R (1992) Incompressible flow computations with stabilized bilinear and linear equal-order-interpolation velocity-pressure elements. Comput Methods Appl Mech Eng 95: 221–242 · Zbl 0756.76048 · doi:10.1016/0045-7825(92)90141-6

[30] Hughes TJR, Franca LP, Balestra M (1986) A new finite element formulation for computational fluid dynamics: V. Circumventing the Babuška–Brezzi condition: a stable Petrov–Galerkin formulation of the Stokes problem accommodating equal-order interpolations. Comput Methods Appl Mech Eng 59: 85–99 · Zbl 0622.76077 · doi:10.1016/0045-7825(86)90025-3

[31] Tezduyar T, Aliabadi S, Behr M, Johnson A, Mittal S (1993) Parallel finite-element computation of 3D flows. Computer 26(10): 27–36 · Zbl 05090697 · doi:10.1109/2.237441

[32] Tezduyar TE, Aliabadi SK, Behr M, Mittal S (1994) Massively parallel finite element simulation of compressible and incompressible flows. Comput Methods Appl Mech Eng 119: 157–177 · Zbl 0848.76040 · doi:10.1016/0045-7825(94)00082-4

[33] Tezduyar T, Aliabadi S, Behr M, Johnson A, Kalro V, Litke M (1996) Flow simulation and high performance computing. Comput Mech 18: 397–412 · Zbl 0893.76046 · doi:10.1007/BF00350249

[34] Tezduyar TE (1999) CFD methods for three-dimensional computation of complex flow problems. J Wind Eng Ind Aerodyn 81: 97–116· doi:10.1016/S0167-6105(99)00011-2

[35] Tezduyar TE (2001) Finite element methods for flow problems with moving boundaries and interfaces. Arch Comput Methods Eng 8: 83–130 · Zbl 1039.76037 · doi:10.1007/BF02897870

[36] Tezduyar TE (2006) Interface-tracking and interface-capturing techniques for finite element computation of moving boundaries and interfaces. Comput Methods Appl Mech Eng 195: 2983– 3000 · Zbl 1176.76076 · doi:10.1016/j.cma.2004.09.018

[37] Tezduyar TE (2007) Finite elements in fluids: stabilized formulations and moving boundaries and interfaces. Comput Fluids 36: 191–206 · Zbl 1177.76202 · doi:10.1016/j.compfluid.2005.02.011

[38] Tezduyar TE (2007) Finite elements in fluids: special methods and enhanced solution techniques. Comput Fluids 36: 207–223 · Zbl 1177.76203 · doi:10.1016/j.compfluid.2005.02.010

[39] Mittal S, Tezduyar TE (1995) Parallel finite element simulation of 3D incompressible flows–fluid–structure interactions. Int J Numer Methods Fluids 21: 933–953 · Zbl 0873.76047 · doi:10.1002/fld.1650211011

[40] Kalro V, Tezduyar TE (2000) A parallel 3D computational method for fluid–structure interactions in parachute systems.

© 2022 FIZ Karlsruhe GmbH

Comput Methods Appl Mech Eng 190: 321–332 · Zbl 0993.76044 · doi:10.1016/S0045-7825(00)00204-8

[41] Tezduyar T, Osawa Y (2001) Fluid–structure interactions of a parachute crossing the far wake of an aircraft. Comput Methods Appl Mech Eng 191: 717–726 · Zbl 1113.76407 · doi:10.1016/S0045-7825(01)00311-5

[42] Stein KR, Benney RJ, Tezduyar TE, Leonard JW, Accorsi ML (2001) Fluid–structure interactions of a round parachute: modeling and simulation techniques. J Aircraft 38: 800–808· doi:10.2514/2.2864

[43] Tezduyar TE, Sathe S, Keedy R, Stein K (2006) Space–time finite element techniques for computation of fluid–structure interactions. Comput Methods Appl Mech Eng 195: 2002–2027 · Zbl 1118.74052 · doi:10.1016/j.cma.2004.09.014

[44] Tezduyar TE, Sathe S, Stein K (2006) Solution techniques for the fully-discretized equations in computation of fluid–structure interactions with the space–time formulations. Comput Methods Appl Mech Eng 195: 5743–5753 · Zbl 1123.76035 · doi:10.1016/j.cma.2005.08.023

[45] Tezduyar TE, Sathe S (2007) Modeling of fluid–structure interactions with the space–time finite elements: solution techniques. Int J Numer Methods Fluids 54: 855–900 · Zbl 1144.74044 · doi:10.1002/fld.1430

[46] Hisada T, Noguchi H (1995) Fundamentals and applications of nonlinear finite element method (in Japanese). Maruzen, Tokyo

[47] Delfino A, Stergiopulos N, Moore JE Jr, Meister JJ (1997) Residual strain effects on the stress field in a thick wall finite element model of the human carotid bifurcation. J Biomech 30: 777–786· doi:10.1016/S0021-9290(97)00025-0

[48] Tezduyar TE (2004) Finite element methods for fluid dynamics with moving boundaries and interfaces. In: Stein E, De Borst R, Hughes TJR (eds) Encyclopedia of computational mechanics, vol 3, Fluids, Chap 17, Wiley, New York

[49] Tezduyar TE, Behr M, Mittal S, Johnson AA (1992) Computation of unsteady incompressible flows with the finite element methods–space–time formulations, iterative strategies and massively parallel implementations. In: New methods in transient analysis, PVP-vol 246/AMD-vol 143, ASME, New York, pp 7–24

[50] Torii R, Oshima M, Kobayashi T, Takagi K, Tezduyar TE (2006) Computer modeling of cardiovascular fluid–structure interactions with the deforming-spatial-domain/stabilized space–time formulation. Comput Methods Appl Mech Eng 195: 1885–1895 · Zbl 1178.76241 · doi:10.1016/j.cma.2005.05.050

[51] McDonald DA (1974) Blood flow in arteries, 2nd edn. Edward Arnold, London

[52] Hayashi K, Handa H, Nagasawa S, Okumura A, Moritake K (1980) Stiffness and elastic behavior of human intracranial and extracranial arteries. J Biomech 13: 175–184· doi:10.1016/0021-9290(80)90191-8

[53] Womersley JR (1955) Method for the calculation of velocity, rate of flow and viscos drag in arteries when the pressure gradient is known. J Physiol 127: 553–563

[54] Ujiie H, Tamano Y, Sasaki K, Hori T (2001) Is the aspect ratio a reliable index for predicting the rupture of a saccular aneurysm. Neurosurgery 48(3): 495–503· doi:10.1097/00006123-200103000-00007

[55] Torii R, Oshima M, Kobayashi T, Takagi K, Tezduyar TE (2007) Numerical investigation of the effect of hypertensive blood pressure on cerebral aneurysm–dependence of the effect on the aneurysm shape. Int J Numer Methods Fluids 54: 995–1009 · Zbl 1317.76107 · doi:10.1002/fld.1497

[56] Holzapfel GA (2003) Biomechanics of Soft Tissue in Cardiovascular Systems, chapter Structural and numerical models for the (visco)elastic response of arterial walls with residual stresses. Number 141 in CISM courses and lectures. Springer, New York

[57] Raghavan ML, Trivedi S, Nagaraj A, McPherson DD, Chandran KB (2004) Three-dimensional finite element analysis of residual stress in arteries. Ann Biomed Eng 32: 257–263· doi:10.1023/B:ABME.0000012745.05794.32

[58] Malek AM, Alper SL, Izumo S (1999) Hemodynamic shear stress and its role in atherosclerosis. J Am Med Assoc 282: 2035–2042· doi:10.1001/jama.282.21.2035

[59] Abruzzo T, Shengelaia GG, Dawson RC III, Owens DS, Cawley CM, Gravanis MB (1998) Histologic and morphologic comparison of experimental aneurysms with human intracranial aneurysm. Am J Neuroradiol 19: 1309–1314

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.

© 2022 FIZ Karlsruhe GmbH