Magin, Richard L.

Fractional calculus models of complex dynamics in biological tissues. (English) Zbl 1189.92007

Comput. Math. Appl. 59, No. 5, 1586-1593 (2010).

Summary: Fractional (non-integer order) calculus can provide a concise model for the description of the dynamic events that occur in biological tissues. Such a description is important for gaining an understanding of the underlying multiscale processes that occur when, for example, tissues are electrically stimulated or mechanically stressed. The mathematics of fractional calculus has been applied successfully in physics, chemistry, and material sciences to describe dielectrics, electrodes and viscoelastic materials over extended ranges of time and frequency. In heat and mass transfer, for example, the half-order fractional integral is the natural mathematical connection between thermal or material gradients and the diffusion of heat or ions. Since the material properties of tissues arise from the nanoscale and microscale architecture of subcellular, cellular, and extracellular networks, the challenge for bioengineers is to develop new dynamic models that predict macroscale behavior from microscale observations and measurements. We describe three areas of bioengineering research (bioelectrodes, biomechanics, bioimaging) where fractional calculus is being applied to build these new mathematical models.

MSC:

92C05 Biophysics
92C37 Cell biology
92C30 Physiology (general)
26A33 Fractional derivatives and integrals
28A80 Fractals

Keywords:

impedance; viscosity; stress

Full Text: DOI

References:

[1] Keener, J.; Sneyd, J., Mathematical physiology, (2004), Springer New York · Zbl 0913.92009
[2] Bar-Yam, Y., Dynamics of complex systems, (1997), Perseus Books Massachusetts · Zbl 1074.37041
[3] Shelhamer, M., Nonlinear dynamics in physiology: A state space approach, (2007), World Scientific Singapore · Zbl 1182.92019
[4] Bruce, E.N., Biomedical signal processing and signal modeling, (2001), John Wiley New York
[5] West, B.J.; Bologna, M.; Grigolini, P., Physics of fractal operators, (2003), Springer New York
[6] Magin, R.L., Fractional calculus in bioengineering, (2006), Begell House Connecticut
[7] Hilfer, R., Applications of fractional calculus in physics, (2000), World Scientific Singapore · Zbl 0998.26002
[8] Kilbas, A.A.; Srivastava, H.M.; Trujillo, J.J., Theory and applications of fractional differential equations, (2006), Elsevier Amsterdam · Zbl 1092.45003
[9] Podlubny, I., Fractional differential equations, (1999), Academic Press New York · Zbl 0918.34010
[10] Samko, S.G.; Kilbas, A.A.; Marichev, O.I., Fractional integrals and derivatives: theory and applications, (1993), Gordon and Breach Switzerland · Zbl 0818.26003
[11] (), No. 378
[12] Anastasio, T.J., The fractional-order dynamics of brainstem vestibulo-ocular neurons, Biological cybernetics, 72, 69-79, (1994)
[13] Anastosio, T.J., Nonuniformity in the linear network model of the oculomotor integrator produces approximately fractional-order dynamics and more realistic neuron behavior, Biol cybern., 79, 377-391, (1998) · Zbl 0918.92003
[14] Thorson, J.; Biederman-Thorson, M., Distributed relaxation processes in sensory adaptation, Science, 183, 161-172, (1974)
[15] Magin, R.L.; Ovadia, M., Modeling the cardiac tissue electrode interface using fractional calculus, Journal of vibration and control, 14, 1431-1442, (2008) · Zbl 1229.92018
[16] Grimnes, S.; Martinsen, O.G., Bioimpedance and bioelectricity basics, (2000), Academic Press San Diego

[17] Ovadia, M.; Zavitz, D.H., The electrode – tissue interface in living heart: equivalent circuit as a function of surface area, Electroanalysis, 10, 262-272, (1998)

[18] Greatbatch, W.; Chardack, W.M., Myocardial and endocardial electrodes for chronic implantation, Annals of the New York Academy of sciences, 148, 235-251, (1968)

[19] Lakes, R.S., Viscoelastic solids, (1999), CRC Press Florida · Zbl 1098.74013

[20] Craiem, D.; Armentano, R.L., A fractional derivative model to describe arterial viscoelasticity, Biorheology, 44, 251-263, (2007)

[21] Craiem, D.; Rojo, F.J.; Atienza, J.M.; Armentano, R.L.; Guinea, G.V., Fractional-order viscoelasticity applied to describe uniaxial stress relaxation of human arteries, Physics in medicine and biology, 53, 4543-4554, (2008)

[22] Puig-de-Morales-Marinkovic, M.; Turner, K.T.; Butler, J.P.; Fredberg, J.J.; Suresh, S., Viscoelasticity of the human red blood cell, American journal of physiology — cell physiology, 293, 597-605, (2007)

[23] Sinkus, R.; Siegmann, K.; Xydeas, T.; Tanter, M.; Claussen, C.; Fink, M., MR elastography of breast lesions: understanding the solid/liquid duality can improve the specificity of contrast-enhanced MR mammography, Magnetic resonance in medicine, 58, 1135-1144, (2007)

[24] Heymans, N., Dynamic measurements in long-memory materials: fractional calculus evaluation of approach to steady state, Journal of vibration and control, 14, 1587-1596, (2008) · Zbl 1229.74016

[25] Bates, J.H.T., A recruitment model of quasi-linear power-law stress adaptation in lung tissue, Annals of biomedical engineering, 35, 1165-1174, (2007)

[26] Bergson, H., Creative evolution, (1998), Dover Edition New York