Prepared by Carlos E. Caicedo-Carvajal, 3D Biotek

References for flow rate/Shear Stress on cells: The Biological Range.

I have decided to put ranges of flow rates to each cell type. Defining the range of shear stress is a bit tricky; it depends on scaffold geometry. As you will see, all porous structures are different from publication to publication, making shear variable and subjective. I am providing a book chapter where the scaffold was tested. One can make an educated guess using the book chapter to determine shear values on scaffold type and flow direction. Disclaimer: In the book chapter, the flow is along the length of the scaffold from left to right. In the bioreactor the flow is from bottom to top.

Literature

(1)

Biotechnol Bioeng. 2012 Jun;109(6):1583-94. doi: 10.1002/bit.24424. Epub 2012 Jan 17.

Influence of flow rate and scaffold pore size on cell behavior during mechanical stimulation in a flow perfusion bioreactor.

McCoy RJ, Jungreuthmayer C, O'Brien FJ.

Source

Department of Anatomy, Royal College of Surgeons in Ireland, 123 St. Stephen's Green, Dublin 2, Ireland; telephone: +353-1-402-2149; fax: +353-1-402-2355; Trinity Centre for Bioengineering, Trinity College Dublin, Dublin, Ireland.

(Note: there is the effect of mechanical stimulation as a function of scaffold pore size and flow rate. I have provided a book chapter along with the PDF library that can give a starting point for researchers who want to explore other 3D pore sizes and flow rates).

(2)

Proc Natl Acad Sci U S A. 2002 Oct 1;99(20):12600-5. Epub 2002 Sep 19.

Fluid flow increases mineralized matrix deposition in 3D perfusion culture of marrow stromalosteoblasts in a dose-dependent manner.

Bancroft GN, Sikavitsas VI, van den Dolder J, Sheffield TL, Ambrose CG, Jansen JA, Mikos AG.

(Note: flow rates at 0.3, 1, and 3-ml/min. For velocity cm/min, the disk had a cross-section area of 0.785 cm^2. Velocity = (ml/min)/area = 0.38, 1.27, and 3.8-cm/min. PDF is available in literature folder) **PDF in file.**

(3)

Proc Natl Acad Sci U S A. 2006 Feb 21;103(8):2488-93. Epub 2006 Feb 13.

In vitro generated extracellular matrix and fluid shear stress synergistically enhance 3D osteoblastic differentiation.

Datta N, Pham QP, Sharma U, Sikavitsas VI, Jansen JA, Mikos AG.

Source

Department of Bioengineering, Rice University, MS-142, P.O. Box 1892, Houston, TX 77251-1892, USA.

(Note: disk were 0.8-cm diameter for an area of 0.50 cm^2. The flow rate is 1-ml/min. The velocity is: 2-cm/min.(PDF is available in literature folder). **PDF in file.**

(4)

Tissue Eng. 2003 Dec;9(6):1205-14.

Application of perfusion culture system improves in vitro and in vivo osteogenesis of bone marrow-derived osteoblastic cells in porous ceramic materials.

Wang Y, Uemura T, Dong J, Kojima H, Tanaka J, Tateishi T.

Source

Age Dimension Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, Japan.

(Note: pre-culture of cells in bioreactor, following in vivo implantation is better than direct in vivo implantation. Related to Biomimetic coated scaffold. Flow rate: 2 ml/hour or 0.033 ml/min).

(5)

Biotechnol Bioeng. 2007 Feb 15;96(3):584-95.

Effects of shear stress on 3-D human mesenchymal stem cell construct development in a perfusion bioreactor system: Experiments and hydrodynamic modeling.

Zhao F, Chella R, Ma T.

Source

Department of Chemical and Biomedical Engineering, FAMU-FSU College of Engineering, Florida State University, Tallahassee, FL 32310, USA.

(Note: 0.1-1.5 ml/min lower limit enhanced proliferation only 1.4 times and upper limit enhanced osteogenesis and proliferation).

(6)

Integration of Experimental and Computational Microfluidics in 3D Tissue Engineering

Manuela T. Raimondi,[1,2] Devin T. Bridgen,[3] Matteo Laganà,[1,2] Beatrice Tonnarelli,[3] Margherita Cioffi,[1,2] Federica Boschetti,[1,2] and David Wendt[3]

[1]LaBS, Department of Structural Engineering, Politecnico di Milano, Milano, Italy, [2]IRCCS Galeazzi Orthopaedic Institute, Milano, Italy, [3]Departments of Surgery and of Biomedicine, University Hospital Basel, Basel, Switzerland, corresponding author: Manuela Teresa Raimondi, address: Laboratory of Biological Structure Mechanics (LaBS), Department of Structural Engineering, Politecnico di Milano, 32, piazza Leonardo da Vinci, 30133 Milano, Italy, phone: +39.02.2399.4306, e-mail: manuela.raimondi@polimi.it **PDF in file.**

(7)

Strategies for Enhancing the Accumulation and Retention of Extracellular Matrix in Tissue-Engineered Cartilage Cultured in Bioreactors

Kifah Shahin[1], Pauline M. Doran[2]*

1 School of Biotechnology and Biomolecular Sciences, University of New South Wales, Sydney, New South Wales, Australia, 2 Department of Chemical Engineering, School of Biological Sciences, Monash University, Melbourne, Victoria, Australia

PDF in file.

(8)

Effects of Initial Seeding Density and Fluid Perfusion Rate on Formation of Tissue-Engineered Bone

WARREN L. GRAYSON, Ph.D.1, SARINDR BHUMIRATANA, M.S.1, CHRISTOPHER CANNIZZARO, Ph.D.2, P.-H. GRACE CHAO, Ph.D.1, DONALD P. LENNON, Ph.D.3, ARNOLD I. CAPLAN, Ph.D.3, and GORDANA VUNJAK-NOVAKOVIC, Ph.D.1

1 Department of Biomedical Engineering, Columbia University, New York, New York
2 Department of Biomedical Engineering, Tufts University, Medford, Massachusetts
3 Skeletal Research Center, Department of Biology, Case Western Reserve University, Cleveland, Ohio

PDF in file.

(9)

Bioreactor Systems for Bone Tissue Engineering

Juliane Rauh, Ph.D.,[1,2] Falk Milan, M.Eng.,[1,2] Klaus-Peter Gu¨ nther, M.D.,[1,2] and Maik Stiehler, M.D., Ph.D.[1,2]

PDF in file.

(10)

Engineering bone tissue from human embryonic stem cells

Darja Marolta,1, Iván Marcos Camposa, Sarindr Bhumiratanaa, Ana Korena,b, Petros Petridisa, Geping Zhangc, Patrice F. Spitalnikc, Warren L. Graysond, and Gordana Vunjak-Novakovica,2

[a]Department of Biomedical Engineering, and [c]Department of Pathology and Cell Biology, College of Physicians and Surgeons, Columbia University, New York,
NY 10032; [b]Blood Transfusion Centre of Slovenia, Ljubljana, SI-1000, Slovenia; and [d]Department of Biomedical Engineering, School of Medicine, The Johns
Hopkins University, Baltimore, MD 21231

PDF in file.

Table I. Compile of fluid velocities and biological effect ton cell types.

Cell Type	*Fluid Velocity (cm/min)*	*Biological Effect*
Osteoblast (2, 3)	0.3	Early Proliferation
Osteoblast (2, 3)	2.5-4.8	Late Mineralization
Mesenchymal Stem Cells (8)	0.3-0.6	Proliferation
Human Chondrocytes (7)	0.04 – 0.11	GAG Retention
Embryonic Stem Cells (8)	0.3 – 3.2	For Differentiation