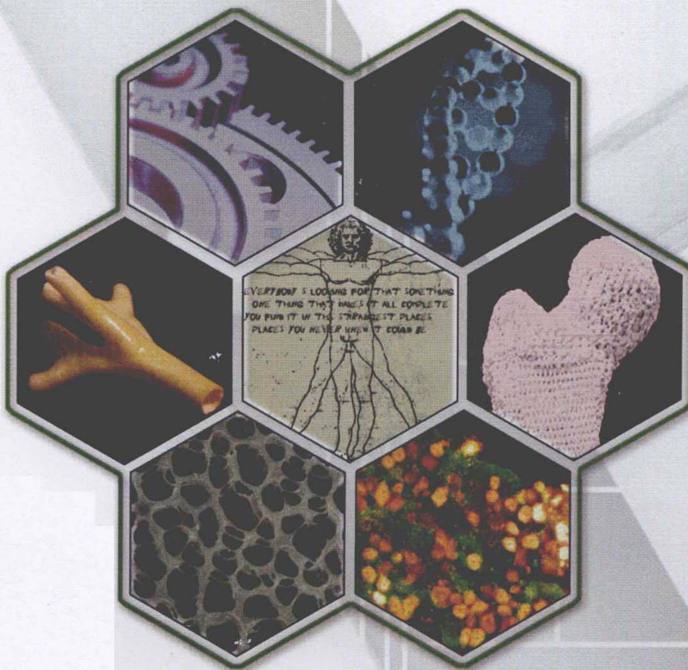
Bio-Manufacturing
International Workshop



生物制造国际研讨会

INTERNATIONAL WORKSHOP ON BIO-MANUFACTURING

资助者 Sponsored by

美国国家科学基金会
National Science Foundation, USA (NSF)

中国国家自然科学基金委员会
National Natural Science Foundation of China (NSFC)

中国机械工程学会
Chinese Mechanical Engineering Society (CMES)

清华大学
Tsinghua University

组织者 Organizer

美国(USA): Myron SPECTOR (Harvard Medical School)
Wei SUN (Drexel University)

中国(China): 清华大学 颜永年 (Yongnian YAN, Tsinghua University)
清华大学 林峰(Feng LIN, Tsinghua University)

时间：6月29日 ~ 7月1日
Date: June 29th ~ July 1st

地点：创新大厦A座会议室 (清华大学东门外)
Location: Meeting Room in Building A, Innovation Center(Plaza) (East Gate of Tsinghua University)

网站(Website): http://mem.drexel.edu/biomanufacturing/index.htm

者：清华大学机械工程系生物制造工程中心
清华大学生命科学与医学研究院生物制造研究所

ed by: Center of Organism Manufacturing Engineering, Department of Mechanical Engineering, Tsinghua University
Center of Bio-Manufacturing Engineering, Institute of Life Science & Medicine, Tsinghua University

生物制造国际研讨会

International Workshop for Biomanufacturing

June 29 – July 1, 2005, Tsinghua University, Beijing, China

29 June

Session 0: Open ceremony and general topic ***Chairman:Prof. Yongnian Yan***

08:30 am – 09:00 am: Workshop-open: welcome ceremony and welcome addresses

- National Science Foundation, USA (Dr. Jian Cao)
- National Natural Science Foundation of China (Dr. Yuanzhong Lei)
- Chinese Mechanical Engineering Society (Dr. Peifan Ding)
- Vice chairman of Tsinghua University Council (Dr. Dongcheng Hu)

Session 1: General ***Chairman: Prof. Friedrich B. Prinz***

9:00 am – 10:30 am:

- Dr. Christine Kelly (National Institute of Health, USA):
  Convergences of Life Sciences and Engineering - Bioengineering Research
- Dr. George Hazelrigg (National Science Foundation, USA):
  Innovative Multi-Disciplinary Research in Manufacturing Machines and Processes
- Dr. Joseph Beaman (The University of Texas at Austin,USA):
  WTEC report and SLS fabrication for prosthesis

Break: 10:30 am – 10:40 am

Session 2: General Tissue Engineering ***Chairman :Prof. Fuzhai Cui***

10:40 am – 12:10 am:

- Dr. Myron Spector (Harvard Medical School,USA):
  Collagen-GAG Scaffolds for Tissue Engineering
- Dr. Changyong Wang (Beijing Institute of Basic Medical Sciences)
  Liquid type I collagen-based cardiac tissue engineering
- Dr. Mauli Agrawal (University of Texas at San Antonio,USA)
  Tissue Engineering Scaffolds: Materials and Architecture

Lunch: 12:10 pm – 1:30 pm

Session 3: General Tissue Engineering ***Chairman:Prof. Mauli Agrawal***

2:00 pm – 3:30 pm:

- Dr. Xuetao Pei (Beijing Institute of Transfusion Medicine)
  Stem Cell Development and Liver generation
- Dr. Shenguo Wang (Chinese Academy of Sciences)
  Cell Scaffold and Its Challenge to Bio-manufacturing
- Dr. Scott Hollister (University of Michigan at Ann Arbor, USA)
  Designer Scaffolds for Tissue Reconstruction

Break: 3:30 pm – 4:00 pm

Discussions Session: 4:00 pm – 5:30 pm

Chairman: Prof. Myron Spector

Welcome Reception, Banquet at Tsinghua Unisplendure International Center
7:00 pm – 8:30 pm

Session 4: Cell Printing and Assembling ***Chairman: Dr. Christine Kelley***

30 June

8:30 am – 10:30 am:

- Dr. Yongnian Yan (Tsinghua university)

  A practice on cell controlled assembly

- Dr. Vladimir Mironov (Medical University of South Carolina,USA)

  How to print organs?

- Dr. Thomas Boland (Clemson University,USA)

  Drop-on-Demand Printing of Cells and Materials for Designer Hybrid ardiovascular Constructs

- Dr. Douglas B. Chrisey (Wright State University,USA)

  Issues for Tissue Engineering by Direct Write Technologies

Break: 10:30 am – 11:00 am

Session 5:Nano-Micro Biomanufacturing ***Chairman: Prof. Joseph J. Beaman***

11:00 am – 12:00 pm:

- Dr. Fritz Prinz (Stanford University,USA)

  Manufacturing of nano-scale probes for observing oxidation reduction reactions in biological cells

- Dr. Xiang Zhang (University of California, Berkeley,USA)

  Micro and Nano-manufacturing: a merge of science and technology

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Lunch: 12:00 pm – 1:30 pm

Session 6:Nano-Micro Biomanufacturing ***Chairman: Prof. Shenguo Wang***

2:00 pm –3:00 pm:

- Dr. Fuzai Cui (Tsinghua)

  Self-assembling of nano-hydroxyapatite/collagen bone graft and its application

- Dr. S.M. Zhang (Huazhong University of Science and Technology)

  Fabrication and characterization of nano-hydroxyapatite / poly (D, L-lactide) composite porous scaffolds for bone and cartilage tissue engineering

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Lab Tour at Tsinghua University: 3:30 pm – 6:00 pm

Biomanufacturing lab

Biomaterial lab

Bioengineering lab

Dinner: 6:30 pm to 7:45 pm

Evening: 8:00 pm to 9:30 pm: Tsinghua-MIT Video Conference on Biomanufacturing

Prof. Linda Griffith and Prof. Yanni Yannas from MIT will attend and present.

Session 7: Computer Aided Tissue Engineering

Chairman: Prof. Xiang Zhang

1 July

8:30 am –10:30 am:

- Dr. Selcuk Guceri (Drexel University,USA)
  PCL Composite Scaffolds for Bone Tissue Engineering
- Dr. Paulo Bartolo (Polytechnic Institute of Leiria, Portugal):
  Biomanufacturing of hard and soft tissues"
- Dr. Michael Liebschner (Rice University,USA)
  Tailoring Tissue Replacement Scaffold Properties Through a Combinatory Approach of Computer-Aided Tissue Engineering and Rapid Prototyping
- Dr. S.H. Masood (Swinburne University of Technology):
  Tissue Engineering of Tri Leaflet Heart Valves

Break: 10:30 am – 11:00 am

Session 8: Computer Aided Tissue Engineering

Chairman: Prof. Guceri

11:00 am – 12:00pm:

- Dr. Chengtao Wang (Shanghai Jiaotong University)
  Prosthesis engineering and bio-manufacturing
- Dr. Dichen Li (Xi'an Jiaotong University)
  Free fabrication of bone scaffolds with microchannels based on stereolithography
- Dr. Andrea Caruso (Therics Co.,USA)
  Commercial Application of TheriForm™ in Orthopedics

Lunch: 12:00 pm – 1:30 pm

Session 9: Computer Aided Tissue Engineering

Chairman: Prof. Bartolo

2:00 pm – 3:40 pm:

- Dr. Jian Liu (Fourth Military University)
  Application of bioactive artificial bone based on RP technique to repair segmental bone defect in big animals
- Dr. Feng Lin (Tsinghua Univesity)
  Fabrication of branchy vessel tissue scaffold with layered wall
- Dr. Xiaohong Wang (Tsinghua University)
  The challenges for liver manufacturing
- Dr. Zhuo Xiong (Tsinghua University)
  Fabrication of porous scaffolds for tissue engineering via low-temperature deposition
- Dr. Wei Sun (Drexel University)
  Computer Aided Tissue Engineering

Break: 3:20 pm – 3:50 pm

Discussions and Summary Session: 3:50 pm – 5:30 pm

Closing Banquet at Teng-Ge-Li Ta-La Restaurant:

5:45 pm to 9:00 pm

Bio-Manufacturing
International Workshop

清华大学机械工程系 激光快速成形中心
清华大学生命科学与医学研究院 生物制造研究所
清华大学国家 CIMS 工程中心 快速成形分中心

CRLF－Center of Laser Rapid Forming,Dept.of Mechanical Eng.Tsinghua University

CBM－Center of Bio-Manufacturing,Institute of Life Science and Medical,Tsinghua University

NATIONAL CIMS Engineering Research Center,Rapid Prototyping Division

颜永年 教授
张人佶 教授
卢清萍 教授
林　峰 副教授
王小红 副教授
吴任东 副教授
熊　卓 博士
袁　达 高工
全永义 工程师
成立华 高级技师

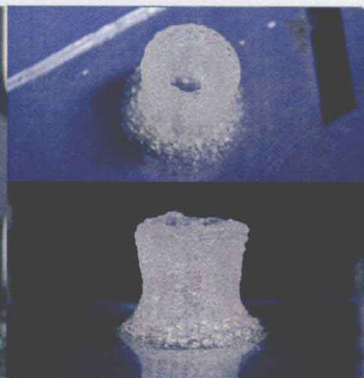
Prof. Yongnian Yan
Prof. Renji Zhang
Prof. Qingping Lu
Dr. Feng Lin
Dr. Xiaohong Wang
Dr. Rendong Wu
Dr. Zhuo Xiong
Engineer Da Yuan
Engineer Yongyi Quan
Technician Lihua Cheng

Team of our research and teaching group

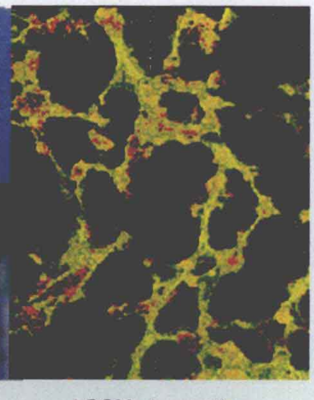
研究方向：	RESEARCH DIVISIONS:
1. 生物体制造	1.Organism-Manufacturing(OM)
2. 材料微输运	2.Materials Droplets Transportation Technique
3. 快速制造	3.Rapid-Manufacturing(RM)
4. 预应力重型装备的 CAD/CAM 和数字模拟	4.CAD/CAM and Simulation of Heavy Equipment of Pre-stress

细胞受控三维组装 Cell Controlled 3D Assembling

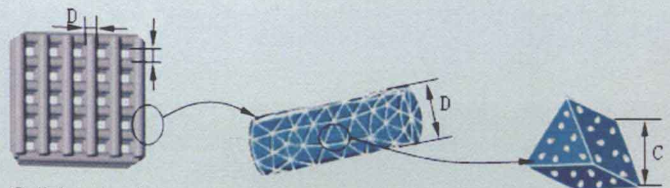
Controlled assembling process
细胞受控组装过程



3D Analogy Tissue Precursor (ATP)
含有活细胞的三维 ATP



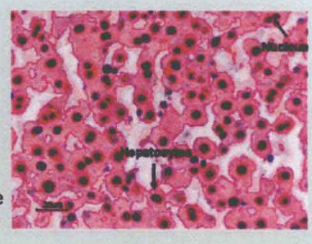
LSCM observation
抗原抗体染色



Cellular structure
蜂窝结构（三级）

Reticular structure
网状结构（二级）

Location structure
单元结构（一级）

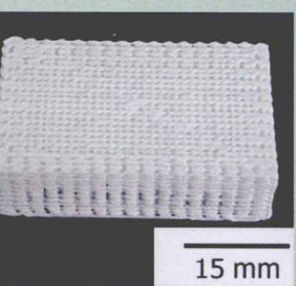


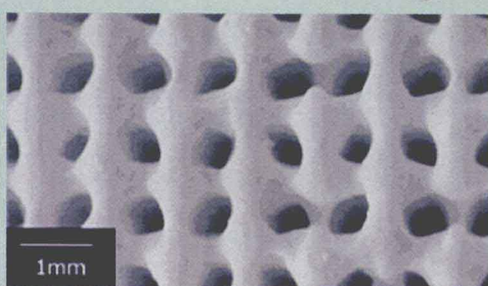
New Type Cell 3D Assembler
新型细胞三维组装机

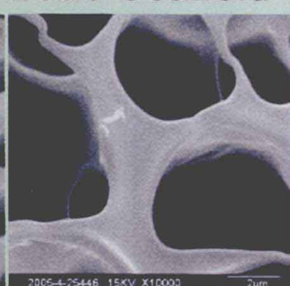
A hierarchical model of one kind of ATP
三级分级结构

Histologic image
组织切片 HE 染色

组织工程支架材料．工艺．设备 Materials.Technologies.Equipments for Tissue Scaffold







组织工程血管支架 Vascular Scaffold

耳软骨支架 Auricle scaffold

隐形牙矫治器 Invisible appliance

三维分级血管支架
Multilayered branchy vascular scaffold

断面图
Section view

耳廓软骨支架
Artificial auricle scaffold

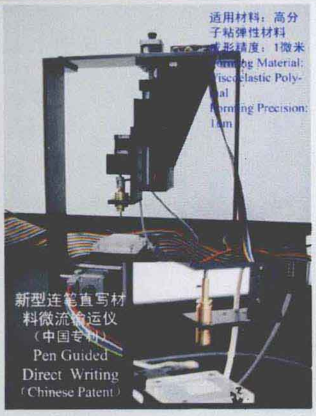
鼠背活皮肤耳廓
Implanted under the skin of a rat

矫治器
Aligner

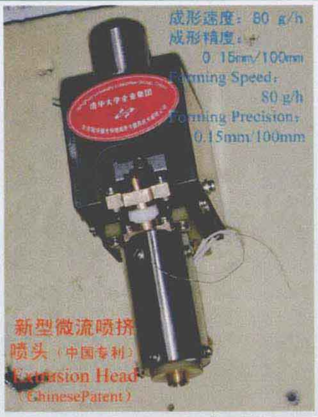
治疗
Therapy

Division II 材料微输运技术 Material Droplets Transporting Technique

连笔直写

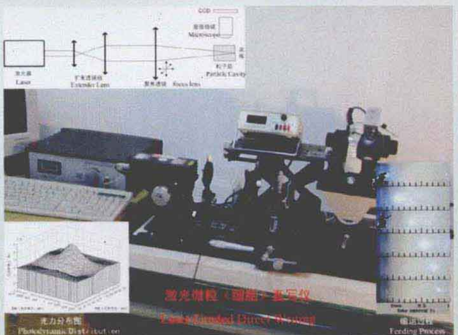


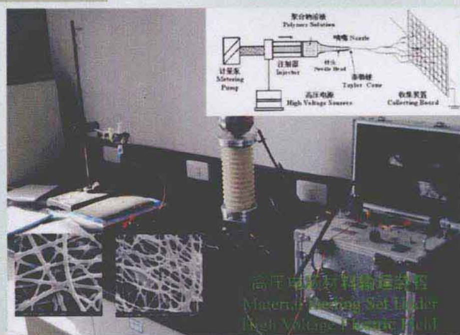
微流喷挤



颗粒粉末输运

激光导引直写
Laser Guided Direct Writing (LGDW)





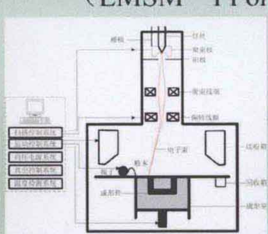
高压电场材料微输送
Material Feeding Under High Voltage Electric Field

Division III 快速制造 RM — Rapid Manufacturing

电子束直接金属成形

电子束选区熔化技术
Electron Beam Selective Melting－EBSM

EBSM－I 设备外形图
（EMSM－I Forming Machine）



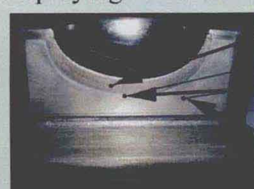
EBSM－I 设备原理图
(Schematic Diagram of EBSM-I)

制件（Arcam）
(the Part from Arcam)

等离子束间接金属成形

等离子喷涂与电弧喷涂
Plasma Spraying and Electric Arc Spraying—PS&EAS

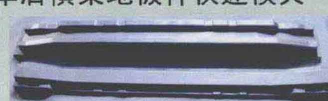
等离子喷涂设备外形图
（PS Forming Machine）



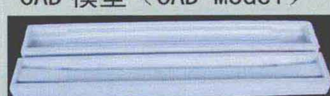
不锈钢快速模具截面图
（Stainless Steel Rapid Model）

采用电弧喷涂制模工艺制造汽车后横梁地板件快速模具

CAD 模型（CAD Model）



RP 原型（RP Prototype）



硅胶模（Silica gel Model）

金属模具（Metel Model）

冲压件（the Pressing Part）

Division IV 预应力重型装备的CAD/CAM和数字模拟
CAD/CAM And Simulation Of Heavy Equipments Of Pre-Stress

研究内容

重型机械设计中的预应力原理
Theory of pre-stress in heavy equipments desgin

重型承载机架和工作缸的预应力设计
Pre-stress design in heavy frame and cylinder

预应力重型装备的液压传动
Hydrostatic transmission in pre-stress heavy equiment

预应力钢丝缠绕结构
Pre-stress Wire Wound structure

模锻和挤压模具的数字模拟
Numerical simulation of die forging and extrusion die

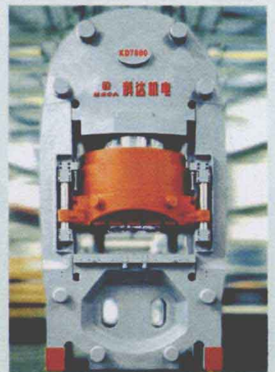
塑性变形工艺数字模拟
Numerical simulation of plastic deformation process

预应力重型装备的计算机控制
Computer control in pre-stress heavy Equipment

重型装备的超高压密封系统
Seal system with very high pressure of heavy equipment

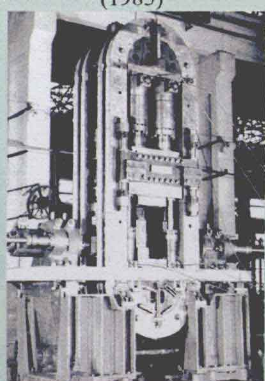
4万吨板料成型压机 已投产
sheet metal forming press
Tonnage:40000 tons
(1994)

1万吨板料成形压机 已制造30余台
sheet metal forming press
Tonnage:10000 tons Made:30
(1985)

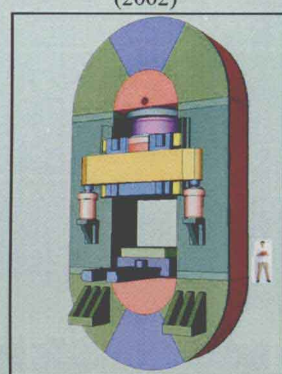


7800吨陶瓷砖压机 已制造200余台
Ceramic tile hydruaulic press
Tonnage:5000 tons Made:200
(2002)

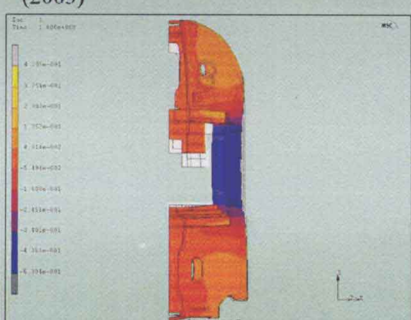
5000吨陶瓷砖压机 已制造50余台
Ceramic tile hydruaulic press
Tonnage:5000 tons Made: 50
(2003)



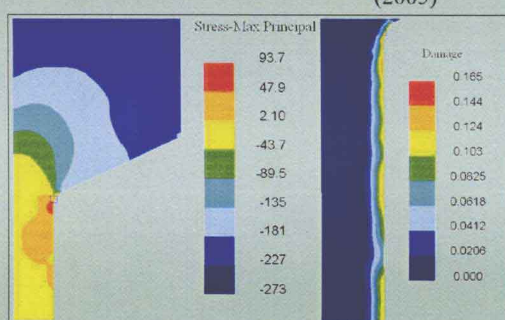
1000吨多向模锻压机 已投产
Multi-ram forging press
Tonnage:1000tons
(1982)



3.5万吨模锻液压机（实施方案）
Die forging hydruaulic press
Tonnage：35000 tons
(2005)



7800吨陶瓷砖液压机承载机器有限元分析
Finite Element Analysis of
Hydraulic Press Frame
(2003)



钢管挤压过程有限元模拟
Finite Element Simulation of
Steel Pipe Extrusion
(2005)

生物制造工程：定义
Bio-Manufacturing Engineering: Definition

生物制造的广义定义：
Bio-Manufacturing (General BM)

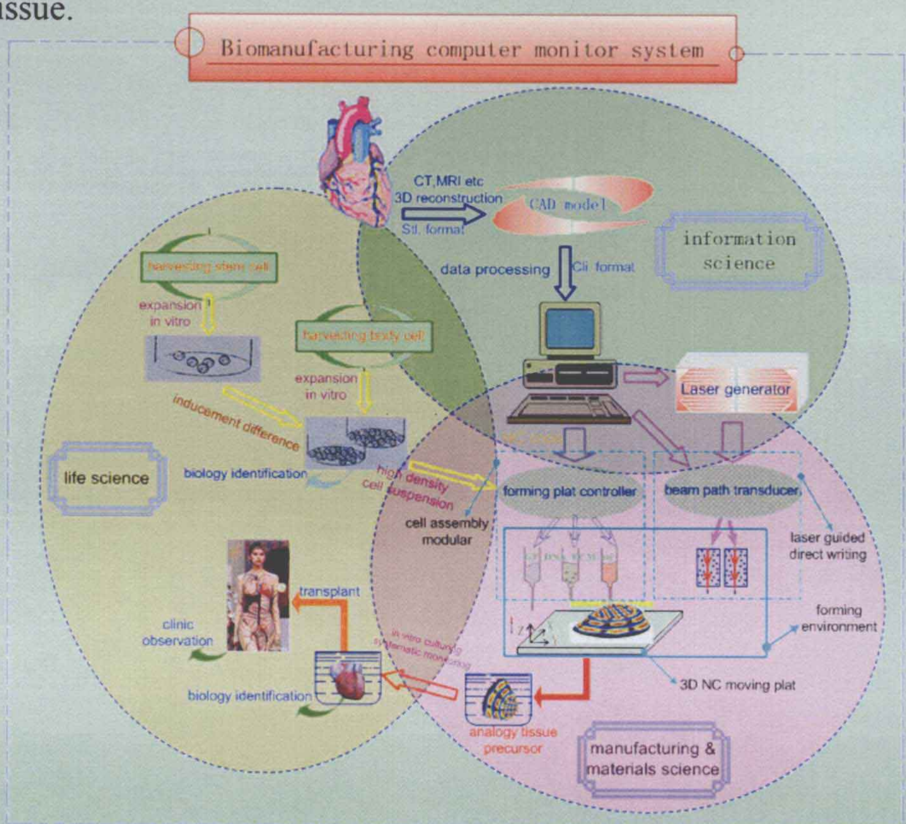
广义生物制造

- 模仿生物体的结构和行为的科学——生物的学习和仿效
  the Science of Simulating of the Structure and Behavior of Organism:Emulation of Life-form
- 利用生物过程进行制造的科学——生物质的制造
  the Science of Manufacturing Based on Bio-Process: Organic-Mass Manufacturing
- 修复和制造生物体的科学——生物体的制造（狭义生物制造）
  the Science of Rehabilitating and Manufacturing of Organism :OM(Special BM)

生物制造的狭义定义——生物体的制造：
OM-Organism Manufacturing (Special BM)

运用现代制造科学和生命科学相结合的原理和方法，通过对多种细胞或细胞团簇的直接或间接受控组装，形成具有新陈代谢功能的生物体——类组织前体，经培养和训练，完成用以修复或替代人体的病损组织的替代物

The organism--3D Analogy Tissue Precursor, which has the function of metabolism is made of various cells or cell clusters with the technologies of direct or indirect controlled assembly. This technology is based on the principle and means combined modern manufacturing science and life science.After cultured and trained,the tissue and organ is formed and can repair or replace the humans’defunct tissue.

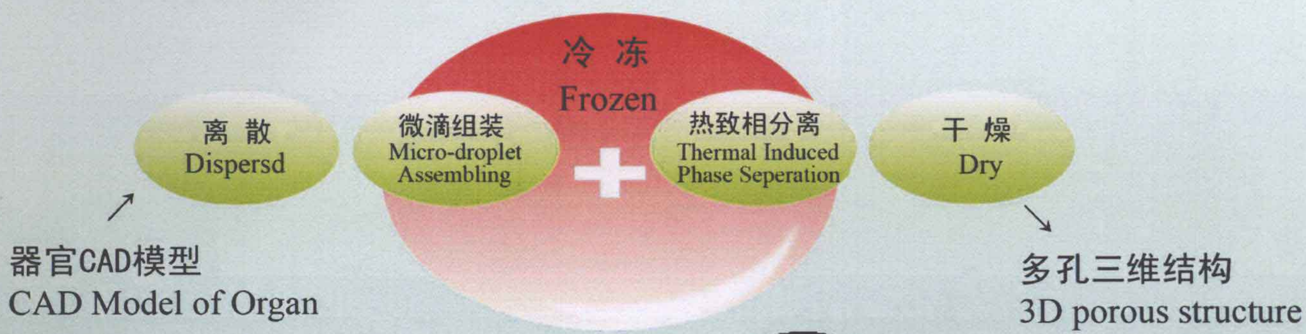


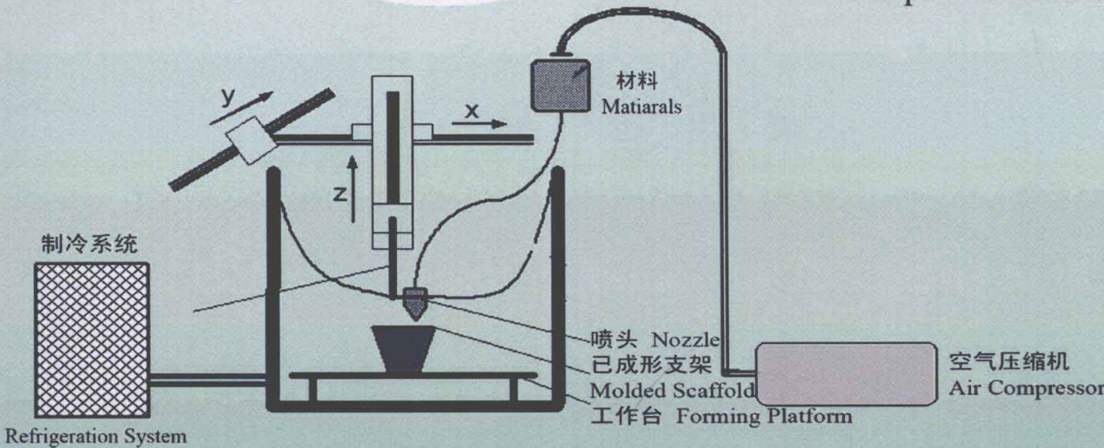
生物体制造学科集成图
The Discipline Intergration of OM (Special BM)

2005. 6. 15 制

生物体制造工程关键工艺
Key Processes of Organism-Manufacturing Eng.

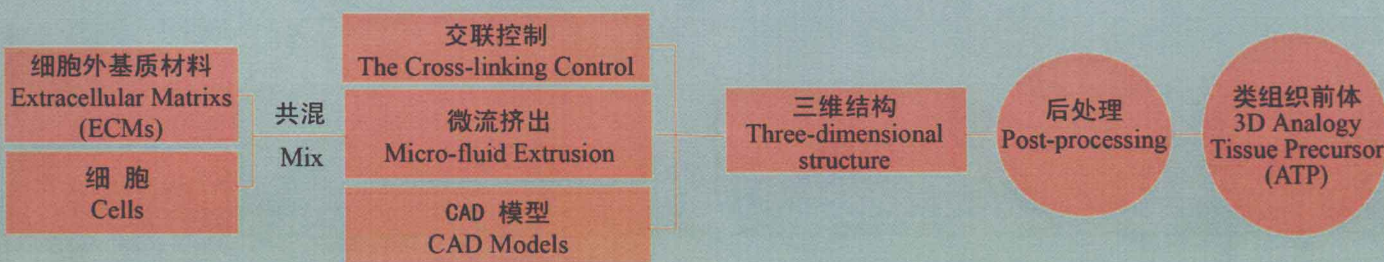
（1）低温沉积制造工艺
Low Temperature Deposition Manufacturing-LTDM

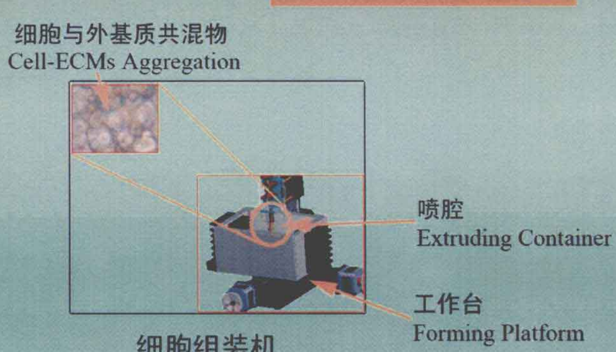




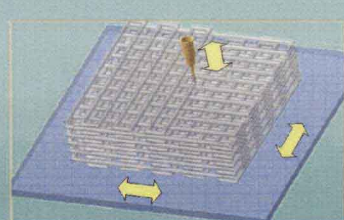
生物材料快速成形开放平台
The rapid forming open platform

（2）细胞受控组装制造工艺
Cell Controlled Assemble Manufacturing-CCAM





细胞组装机
Cells Assembler



可三维运动的工作台
3D Micro-positioning Platform

Research Programs and Funding Opportunities at the National Institute of Biomedical Imaging and Bioengineering

Christine A. Kelley, Ph.D.
Director, Division of Discovery Science and Technology

International Workshop for Biomanufacturing
June 29-July 1, 2005
Tsinghua University
Beijing, China

1

Outline of Presentation

- Quick tour of the NIBIB
- Snapshot of NIBIB funded research
- Research funding and training opportunities

2

Quick tour of the NIBIB

3

The NIBIB is the Newest Institute at the National Institutes of Health

Brief History:

- December, 2000 — After many years of lobbying by the imaging and bioengineering communities, the NIBIB was signed into law by President Clinton.
- April, 2002 — First grants to support research were awarded
- September, 2002 — Roderick Pettigrew, Ph.D., M.D. joined the NIBIB as the first Institute Director
- Personnel: — Currently about 50 staff members

4

The NIBIB Staff

5

NIBIB Budget

- FY 2005 – NIBIB Conference
  $298.2 Million
- FY 2006 – President's Budget Request for NIBIB
  $299.8 Million

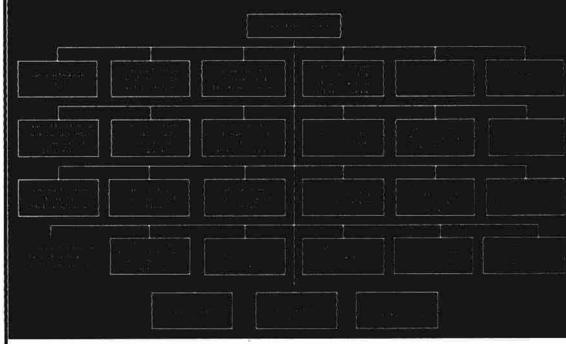
6

NIH vs. NIBIB Appropriations
Dollars in Millions

*NIBIB established December 2000—first appropriation was FY 2002

7

National Institutes of Health



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NIBIB Mission

Improve human health by leading the development and accelerating the application of biomedical technologies. The Institute is committed to integrating the physical and engineering sciences with the life sciences to advance basic research and medical care.

NIBIB Vision

To profoundly change health care by pushing the frontiers of technology to make the possible a reality.

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A big challenge for the NIBIB is promoting multidisciplinary research

1. **Clinicians, biologists and engineers speak in different languages**
2. **Clinicians and biologists may not know what is technically possible; engineers may not know the biomedical problems.**
3. **Continued, ongoing collaboration essential**

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NIBIB Research Programs in Biomedical Imaging

- **Imaging device development**
- **Image computation, display, perception, and screening**
- **Contrast agent and molecular probe development**
- **Image-guided therapies and interventions**
- **Development of low-cost medical imaging devices**
- **Multi-modality imaging**
- **Methods for non-invasive cell and molecular imaging**

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Scope of Scientific Programs
Division of Discovery Science and Technology

- **Advanced Biomaterials**
- **Bioinformatics**
- **Biomechanics and rehabilitation engineering**
- **Drug and gene delivery systems and devices**
- **Image processing, displays, and perception**
- **Mathematical models and computational algorithms**
- **Medical devices & implant science**
- **Platform technologies (lab-on-a-chip)**
- **Remote diagnosis and therapy (telehealth)**
- **Sensors**
- **Surgical tools and techniques**
- **Tissue engineering**

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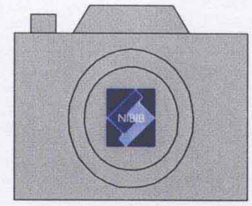
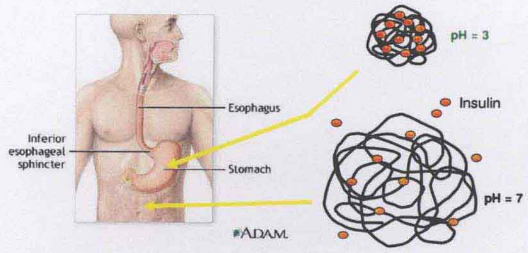
Snapshot of funded NIBIB grants



DRUG DELIVERY

Development of a pH Sensitive Complex Hydrogels for Oral Protein (Insulin) Drug Release

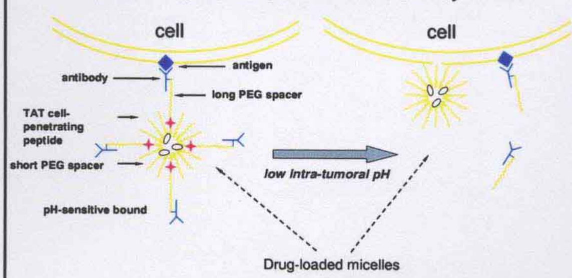
Nicholas A. Peppas, Ph.D., UT Austin EB246



<0.1% of insulin taken orally retains activity by the time it reaches the blood stream. This investigator is developing a pH responsive hydrogel that at low pH is in a collapsed conformation that protects the proteins in passage thru the stomach and as the pH rises in the intestines, the hydrogel swells and rreleases the protein where it can be absorbed into the blood stream.

Micellar Carriers for Poorly Soluble Drug Delivery

Vladimir P. Torchilin, Ph.D., Northeastern University EB1961



Micelles prepared from conjugates of soluble biocompatible polymers, The micelles are loaded with poorly soluble anticancer drugs in the hydrophobic core and are modified with antibodies to a particular tumor antigen for targeted delivery and TAT peptides for intracellular delivery.

Biosensors

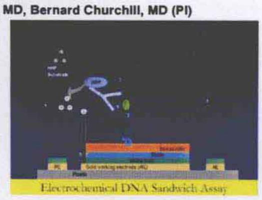
The UCLA Urosensor

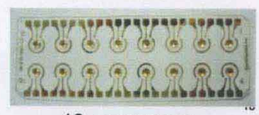
Joseph Liao, MD, David Haake, MD, Bernard Churchill, MD (PI)

Goal: Development of a microfluidic, point-of-care device for rapid detection of bacteria which cause urinary tract infections. Very prevalent in children with spina bifica

FEATURES:

- Team of clinicians, engineers and microbiologists.
- Electrochemical-based sensor
- RNA target
- Rapid and sensitive detection (5 min. assay)





16 sensor array

SURGICAL TOOL DEVELOPMENT

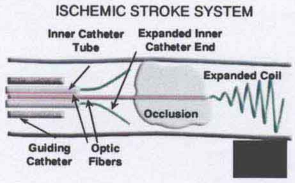
Development of a Shape Memory Polymer Device for Treating Stroke

Duncan Maitland, PhD

Lawrence Livermore National Laboratory

- **Mechanical clot extraction catheter with shape memory fiber attached to optical fibers**
- **When laser turned on, polymer transitions from straight shape to coiled shape.**

ISCHEMIC STROKE SYSTEM



NIBIB Bioengineering Research Partnership

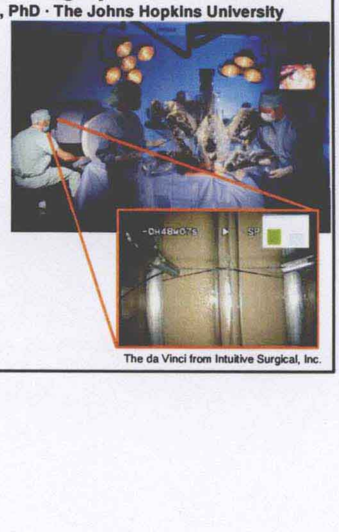
Haptics for Robot-Assisted Minimally Invasive Surgery

Allison M. Okamura, PhD · The Johns Hopkins University

Goal: To provide haptic (synthetic force and/or tactile sensations) feedback to a surgeon via telemanipulator to improve safety and efficacy of surgical robots

Methods: Force sensor design and control algorithms

Early Results: Force feedback alone is sufficient to improve performance, and sensory substitution of haptic information is effective



The da Vinci from Intuitive Surgical, Inc.

Image-Guided Intervention in Neocortical Epilepsy

Dr. James Duncan, Yale University, R01 EB000473

- Dr. Duncan heads a BRP – (Yale, Albert Einstein College of Medicine, the University of Minnesota, and BrainLAB,) a mulitdisciplinary team specializing in image-guided surgery.
- MRI of a patients brain. Overlay shows where the brain is active while performing a language task as quantified by fMRI and EEG.
- The integration of this data into a common space is used to identify the epileptogenic tissue and surrounding regions to plan and guide neurosurgery

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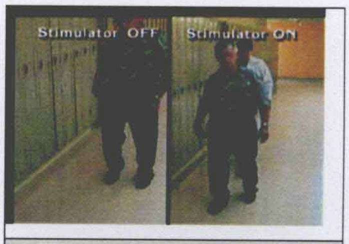
Rehabilitation Engineering

Deep Brain Stimulation for Parkinson's Disease

Dr. Hunter Peckham, Case Western Reserve University



DeepBrain_CCF

A thin wire is implanted deep into the brain in an area involved in motor control. The wire comes out of the skull, under the skin to the pectoral area where it connects to a pacemaker-like device.

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Telehealth
Development of Multi Sensor Fusion Algorithms for Remote Circulatory Monitoring

H. Harry Asada
Massachusetts Institute of Technology

Andrew Reisner
Massachusetts General Hospital

Wearable Cuff

The MIT Ring Sensor

Developing a multi-modality wearable ring sensor system, through the development of novel multi-sensor fusion algorithms, to enable long-term, remote circulatory monitoring. The signals are transmitted locally to a PDA then over the internet to the physicians office.

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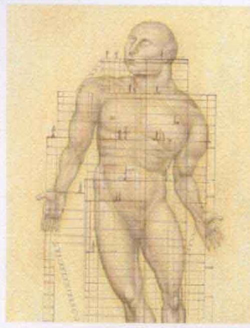
Tissue Engineering and Regenerative Medicine

- Engineering of tissue *in vitro* for subsequent implantation in vivo, to repair, replace, maintain or enhance organ function.
- Regeneration of tissue *in vivo* for the purpose of repairing, replacing, maintaining, or enhancing organ function.



NIBIB

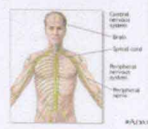
Application Areas

Myocardial Patch

Skeletal Muscle

Heart Valve

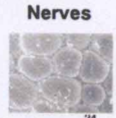
Liver



Nerves

Vascular Graft

Cartilage and Bone



Adipose Tissue

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Tissue Engineering Program Current Portfolio

Scientific Subcategory	# of Active Grants	Total Costs (million $)
Biomolecules and Cells	10	3.4
Scaffold Development / Tissue-engineered therapies	24	6.6
Enabling Technologies	10	2.8
Total	**44**	**$12.8 M**

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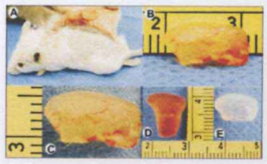
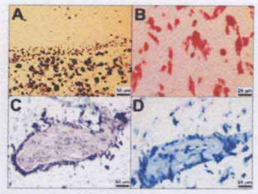
Functional Tissue Engineering of Articular Condyle for Replacement

Jeremy Mao, R01 EB2332, University of Illinois at Chicago



Tissue-engineered human-shaped mandibular condyle from rat mesenchymal stem cells



Histology following 8 wks of *in vivo* implantation showing both chondrogenesis and osteogenesis from mesenchymal stem cells.

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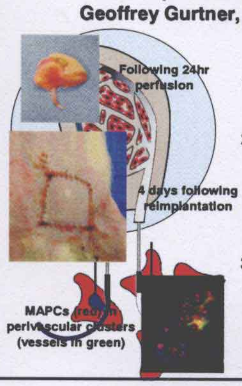
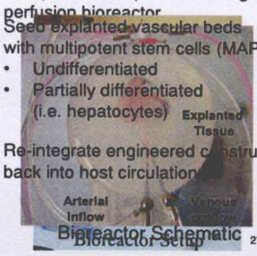
Explanted Vascular Beds as a Scaffold for Complex Tissue Engineering

Geoffrey Gurtner, NYU School of Medicine



1. Sustain viability of explanted vascular bed (the scaffold) *ex vivo* using a perfusion bioreactor
2. Seed explanted vascular beds with multipotent stem cells (MAPC)
   - Undifferentiated
   - Partially differentiated (i.e. hepatocytes)
3. Re-integrate engineered construct back into host circulation



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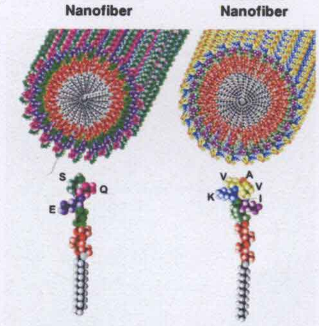
Regenerative Scaffold Technologies For CNS & Diabetes

Sam Stupp, PI, Northwestern



Nanofibers Customized for Neural Progenitor Cell Differentiation

IKVAV epitope known as a neurite sprouting/guiding epitope, present in the extracellular protein laminin

***Science* 2004**

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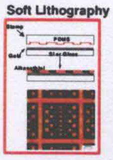
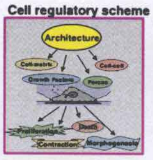
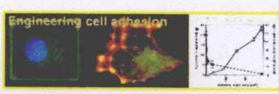
Use of Micropatterning Techniques to Control Stem Cell Differentiation

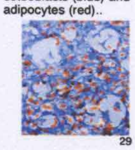
Chris Chen, Johns Hopkins University







Human mesenchymal stem cells differentiated into osteoblasts (blue) and adipocytes (red)..



- Use of micropatterning techniques to control mesenchymal stem cell shape.
- Cell shape induces molecular signals controlling differentiation.
- Stem cells forced into spherical shapes become fat cells, those allowed to stretch and flatten become bone cells.
- The research offers a means to control stem cell differentiation with the long-term goal of regenerating or repairing damaged tissue

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Potential Future Directions Tissue Engineering

1. **Development of enabling technologies for tissue engineering with an emphasis on: 1) real-time, non-destructive tools to assess function; 2) computer-aided tissue engineering, and; 3) bioreactor and tissue preservation technologies.**
   - Background: Tools and technologies currently available are limited.
   - Direction: Lead the development of enabling technologies that are crucial in aiding and translating tissue engineering applications to improve human health
2. **Development of engineered 3D human tissue model systems for basic and clinical research as well as drug discovery and development.**
   - Background: Inaccuracies and high costs of animal studies to predict human response, safety and efficacy.
   - Direction: Promote the development of engineered 3D human tissue model systems that closely mimic the complex environment and interaction of humans organ systems.

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