Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

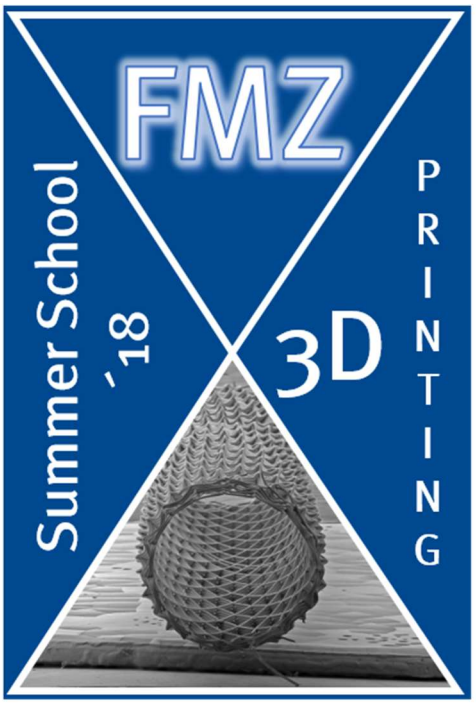
Fakultät für
CHEMIE UND
PHARMAZIE

Summer School

3D-Printing Technologies

Photochemical and Electrohydrodynamic Techniques

Program



Organization

Prof. Dr. Paul Dalton

Dr. Daniel Bellinger

Special Thanks to

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AOK Bayern

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Dear participants,

As you arrive in Würzburg and see at the vineyards around this historic city, you share the same view of many famous scientists who lived here. A total of 14 Nobel Laureates have researched and taught at the University of Würzburg, with the last one awarded in 2008. Only 200m away from the conference venue is the laboratory of Wilhelm Conrad Röntgen, where X-rays were discovered in November 1895. His experiments combined vacuums, electricity and exotic materials and resulted in a discovery that changed the world forever. Albert von Koelliker is considered by many as the modern-day father of histology, and published a seminal atlas on cell morphogenesis – his building is even closer to the lecture hall than Röntgen's. These two scientists were colleagues and, in a famous January 1896 local lecture (only 2 months after its discovery) a live demonstration of X-rays using Koelliker's hand provided a stunning example of how this new radiation could be applied to medicine. Röntgen was trained as a physicist, but had a colossal impact on medicine.

Ten meters away, just next door to the summer school lecture theatre, is the building for Hermann Emil Fischer, who won a Nobel Prize in Chemistry in 1902 for his advances in carbohydrate chemistry. The late 19th to early 20th Century was a particularly exciting period for science and engineering, and allowed the 2nd Industrial Revolution (electricity-driven mass production) to entrench itself and alter societies in incredible ways.

Our world today is equally exciting - the rate of discoveries continues unabated as we enter the 4th Industrial Revolution (cyber-physical systems). 3D printing is a key enabling technology in this context, and offers multiple career opportunities. It is what brings us all together – students and teachers – to work out how we can use 3D printing to do extraordinary things. For some, it is to fabricate high-performance shoes. For others, it is to provide medicine with new treatments of injury and disease. An even more ambitious goal is to make this available to everyone, irrespective of their location or salary. Effective products on demand and customized, for a fraction of today's cost sounds like a dream, but is actually within reach.

You are essential for this future to occur. Together, our interest in 3D printing can be applied to solving some of the world's greatest challenges. While we have gathered experts on many 3D printing technologies, it will be the audience that delivers this change. So while I welcome you to Würzburg, I also challenge you to engage, discuss and get to know your colleagues. There are no exams or group projects within the summer school, but numerous breaks and activities. We will tour the city, have a poster session, visit the vineyards and learn about the history of Würzburg, including the Röntgen Museum. Use this opportunity to meet your colleagues and engage in 3D printing discussions. Dream, imagine and think about what can be done better, done differently?

I welcome you to Würzburg, for an engaging exchange of minds.

Sincerely,

Prof. Dr. Paul Dalton

Index

Welcome

Front view of the world heritage "Residence of Würzburg"[1]

Würzburg is a city in Franconia, a region located in northern Bavaria, Germany. It is beautifully located at the river Main. Würzburg is the local capital city of lower Franconia.

One of the first settlements date back to the Bronze Age, whereas they were located at the site of river main where later the Fortress Marienberg refuge castle was build. So, this first settlements can be assigned to the Celtic tribes. Later in the 5th to 6th century the Alamanni and Franks came to the territory and settled down. The Christianization begun in 686 and was initialized by Irish missionaries. One of the missionaries' name was Kilian who is a patron saint of the city.

The first diocese was founded in the 8th century. Since the foundation on the bishopry in 742, Würzburg has been the clerical center of the area. During the Peasant's Revolt in 1525 the town sided with the peasants, who tried unsuccessfully to storm the fortress. This sealed the fate of Würzburg's famous woodcarver, alderman and mayor, Tilman Riemenschneider. In the following decades strong clerico-worldly sovereigns ruled the town, among them prince-bishop Julius Echter of Mespelbrunn. The town reached its zenith under the leadership of the art loving family of Schönborn. For them, Balthasar Neumann built the "castle of castles" - the Residenz – between 1720 and 1744 including the famous staircase, where the Venetian Giovanni Battista Tiepolo created the world's largest ceiling fresco. After various political quarrels Würzburg became Bavarian in 1814. On March, 16th, 1945 the town was almost completely destroyed within 17 minutes. She owes her reconstruction to the extreme engagement of her inhabitants. Today Würzburg has 134.000 inhabitants, is the Unterfranken county seat and a young and lively city with around 30000 students. The surrounding vineyards, the river Main and many sightseeing points invite you to saunter around.

The universities history is a long story and connected to the clerical world of the Prince-Bishop. The first foundation dates to 1402. Related to this first foundation the Julius-Maximilians-Universität (JMU) belongs to the group of the four oldest universities in the todays area of Germany. The permanent foundation of the university was in 1582 and initiated by the Prince-Bishop Julius Echter von Mespelbrunn. In her long history many famous scientists have researched in Würzburg. In total 14 Nobel Laureates can be associated with the JMU. In the field of chemistry four scientists can be found within this selected group: Emil Fischer, Svanthe Arrhenius, Eduard Buchner, Walther Nernst and Ernst Michel.

The faculty of chemistry and pharmacy is located at many different places in Wuerzburg. This geographic diversity can also be found in the science made in the various institutes of the faculty.

[1] Original work from Christian VisualBeo Horvat @ CC-BY 2.0, *https://de.wikipedia.org/wiki/Datei:Residenz_Wuerzburg_Vorderan.jpg.*

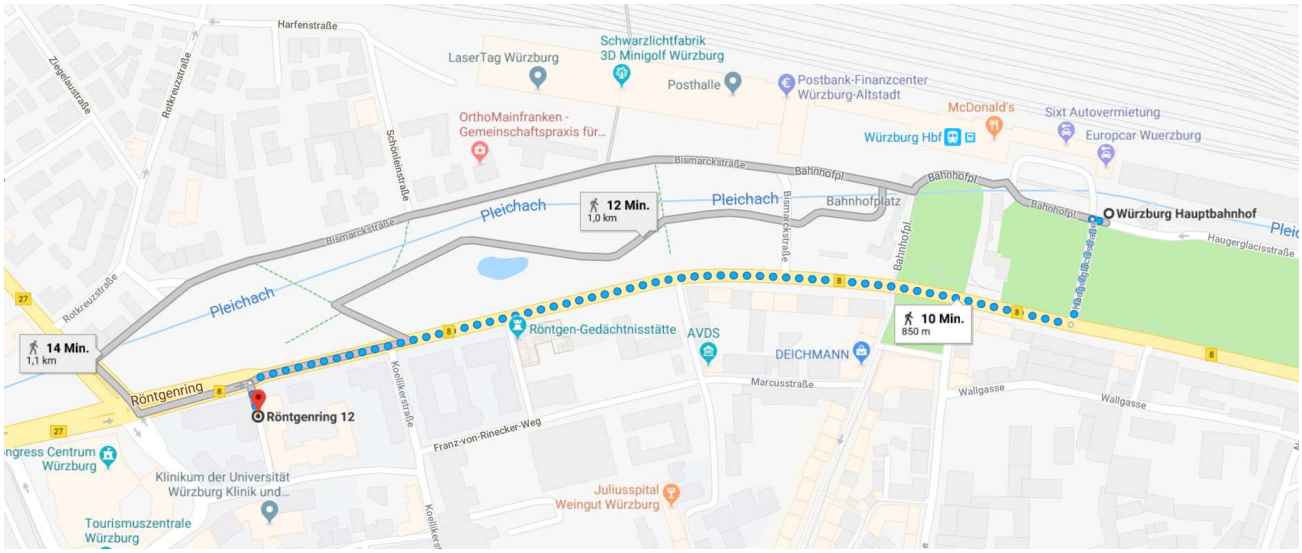
One part of the institutes is located at the Hubland farther outside the center. The organic, inorganic, physical, theoretical and biochemistry, as well as pharmacy and food chemistry can be found there. The summer school is located on the other side of the city and around the historical buildings of the "old chemistry institute" which are close to the historical part of the city. The chair of chemical technologies of material syntheses and the chair for functional materials in medicine and dentistry can be found there. The chemistry at the Röntgen Ring, nearby the labs of Wilhelm Conrad Röntgen, is fascinating and diverse.

The University of Würzburg has become one focal point for 3D printing research. Together with the Universities of Bayreuth and Erlangen, we have been awarded the most prestigious public-funded program provided by the German Research Foundation on the topic "Biofabrication". Led by Professor Jürgen Groll, this group focuses on the basic science behind 3D bioprinting, with an eye to translating such technologies into practice. The International Society for Biofabrication will be held in Würzburg in late October (www.biofabrication2018.org), while in 2015 the university established the first Master's Degree in biofabrication. Professor Paul Dalton who pioneered melt electrostatic writing (MEW), and is hosting this conference, has a laboratory with some of the best MEW printers in the world. The future of 3D printing is exciting, and the considerable effort and infrastructure put in place at the University of Würzburg ensures that this region will play a role in this 21st Century technology.

General Information

Arrival (by train)

The summer school location is very close to the main central station. It is a ten-minute walk and about 850m away (see maps.google.com screenshot or QR-Code). The registration, welcome event location and the summer school lecture rooms will be indicated by signposts.



Wifi-Connection

You can use the **eduroam** network with the login from your home university or the Summer School account for **RZUW** network with the following login details:
Pre-Shared-Key: Julius-Echter
Login: print18
Password: print18

Registration

The registration is open during the welcome event. The welcome breakfast will be in the institute at Röntgenring 11, Seminar Room 001. The location will be reachable by following the postsigns.

Lectures

The lectures will take place in the Külpe lecture hall in the old eye clinic. This is located at the Röntgenring 12.

Course documentation and media

The materials presented in summer school will be available on the moodle platform wuecampus2. The access to the course related to summer school is possible via the following link:

https://wuecampus2.uni-wuerzburg.de/moodle/course/view.php?id=28768

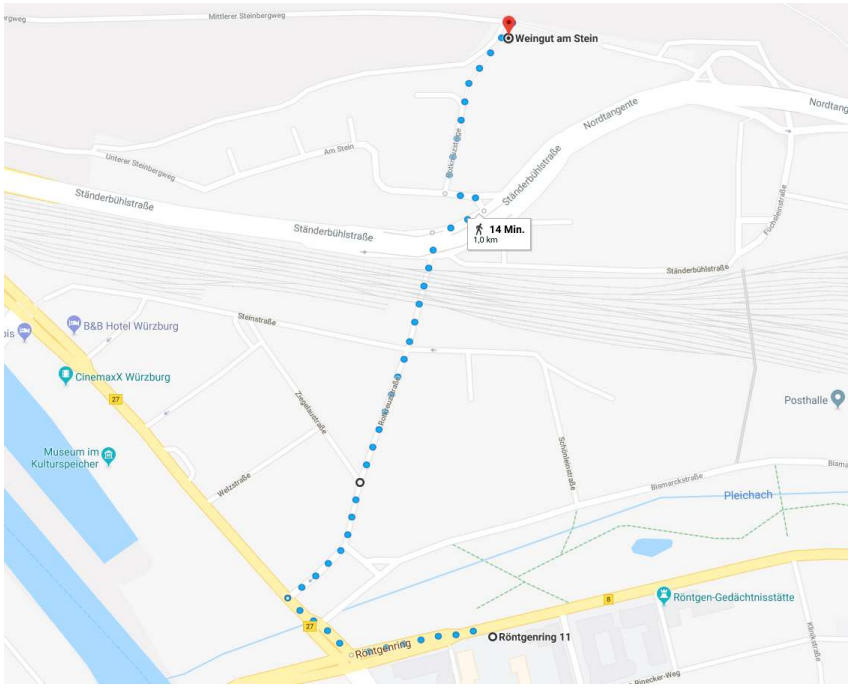
The access is granted via the following key: **3dprinting**

Lunch

The costs for lunch is included within the summer school and will be served in the Mensa of the old eye clinic at Röntgenring 12. The location of the Mensa will be shown by signposts and is in the same building as the Külpe lecture hall.

Visit of Wein am Stein *(Monday, 5.15pm, Venue: in front of Röntgenring 11)*

At the first day we will visit one of the traditional wine festivals which are part of the Franconian wine culture. This festival will take place at the location called “Wein am Stein”. We will go together from the institute to the location of the festival. It is about 1.2 Km away. For those who want to drive there by car we can organize cabs. The entrance to Wein am Stein is included in the contribution of expenses.



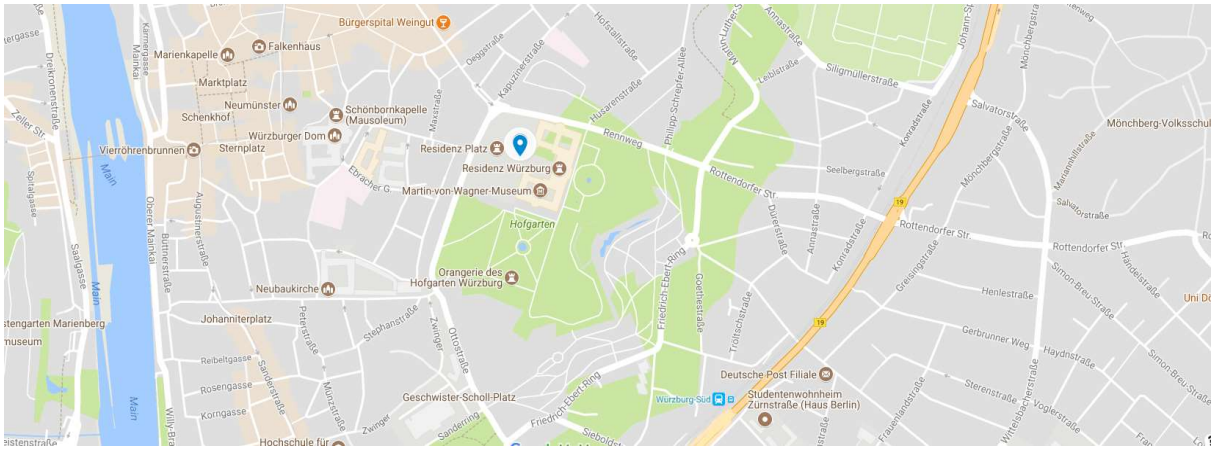
Poster session *(Tuesday, 4.30pm, Venue: seminar room 001, Röntgenring 11)*

There will be poster walls and pins available in the seminar room. The posters can be hung during lunch break on Tuesday.

Wine tasting in the residence wine cellar *(Tuesday, 7.00pm, Venue: in front of the Residence at Franconia fountain)*

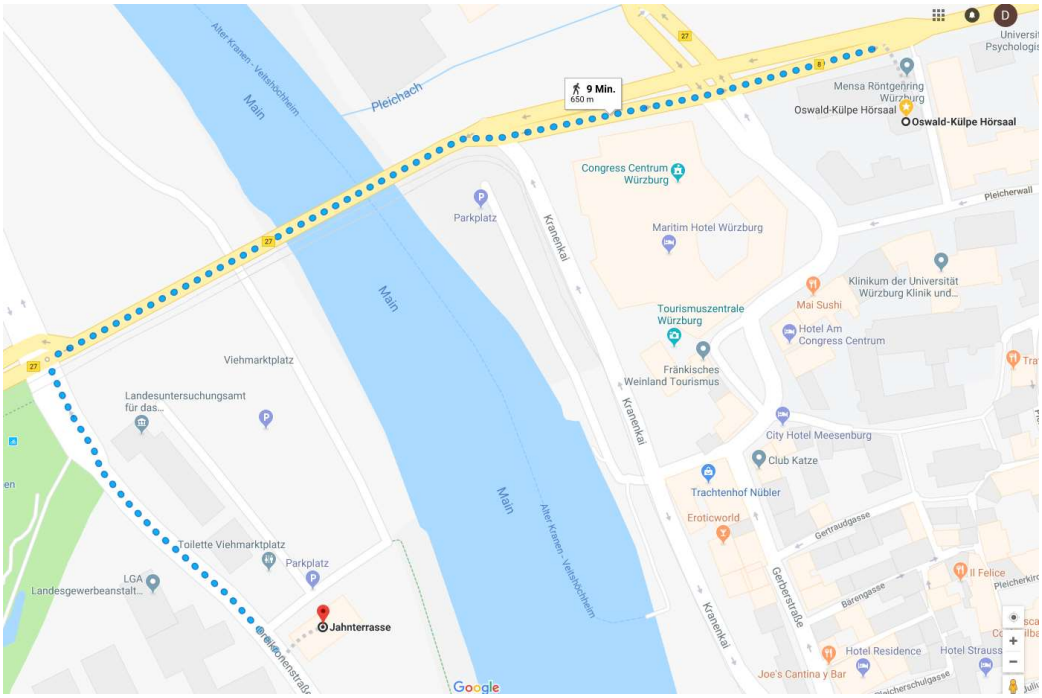
For the wine tasting we will meet at the Franconia fountain in front of the Residence of Wuerzburg at 7 pm.

The cost of the wine tasting is already included in the contribution of expenses.



Wednesday dinner *(6.30pm)*

For dinner on Wednesday we will meet at the “Biergarten Jahnterasse” which is located at the other side of river Main and 650m away from the summer school location.



Guided City tour *(Thursday, 5pm, Venue: Röntgen museum)*

The tour will start at the Röntgen museum and will have a duration of 2 hours.

Program

Time	Monday 16/07	Tuesday 17/07	Wednesday 18/07	Thursday 19/07	Friday 20/07
8.30		**Uwe Gbureck** Inorganic 3D Printing			
9.00	Registration, Welcome Breakfast Get-Together	**Boris Holzapfel** 3D Printed Implants	**Paul Dalton** Electrospinning	**Dirk Grijpma** Stereolithography	**Larisa Florea** Two-photon Polymerization
9.50		**Coffee Break**	**Coffee Break**		**Coffee Break**
10.20		**Dirk Schubert** Introduction to Rheology	**Paul Dalton** Melt Electrowriting (MEW)	**Coffee Break**	**Braden Ball** *Carbon3D, USA* Digital Light Synthesis
11.30	**Paul Dalton** Welcome	**Short Break**	**Short Break**	**Georg Schwalme** Selective Laser Sintering	**Short Break**
12.00	**Brian Derby** The Evolution of 3D Bioprinting	**Aurelian Forget** Introduction to Hydrogels	**Felix Wunner** A Systems Engineering Approach to MEW **Ouafa Dahri** Using MEW to fabricate 3D cell culture systems	**Short Break** **Patrycja Szymczyk** 3D Metal Printing	**Vladimir Mironov** *3D Bioprinting Solutions* The Future of 3D Bioprinting
13.00	**Lunch**	**Lunch**	**Lunch**	**Lunch**	Closing Remarks & Departing Lunch
14.00	**Senentxu Lanceros-Mendes** 3D Printing in Context	**Jürgen Groll** Fundamentals of 3D Bioprinting	**Daniela Lössner** 3D Printing in Cancer Research	**Bastian Rapp** 3D Printing with Liquid Glass	
14.40	**Paul Dalton** Fused Deposition Modelling		**Filippos Tourlomousis** Cell shape metrology using MEW	**Paul Dalton** Free-Form Writing	
	Short break	**Short Break**	**Short Break**	**Short Break**	
15.20	**Paul Dalton** 3D Printing Design	**Zhilian Yue** Biologically Derived Polymers as Bioinks	**Elena De Juan Pardo** Mechanical Properties of MEW Scaffolds	**Robert Luxenhofer** 3D Printing with Polyoxazolines	
16.00	**Coffee Break**	**Coffee Break**	Facility Tour	Free Time	
17.00	**Paul Dalton** G-Code Basics	Poster Session		Guided City Tour	
18.00	Visiting the Wein am Stein	Free Time	Beer Garden (Jahnterrasse)		
19.00		Wine Tasting			
20.00					

Speakers

Biographies

Braden Ball

Carbon 3D

Topic

Digital Light Synthesis

Bio

Braden Ball is program manager at Carbon, Inc. He studied at Brigham University where he obtained his bachelor in Manufacturing Engineering Technology. Then he moved to MIT and obtained his master degree in Engineering. Besides the master in engineering he also extent his studies and finished a MBA at Sloan School of Management (MIT). He started his carrier by doing a great job at Caterpillar Inc. from 2008 to 2013 during he studied and was part of the professional development program. He moved on to Tesla Motors and stayed there until 2016. In 2016 he joined the team at Carbon Inc. and is responsible for program management.

Paul Dalton

University of Würzburg

Topic

Melt Electrowriting

Bio

Paul Dalton is an expert in the field of melt electrospinning writing. He obtained his bachelor in multidisciplinary sciences from Perth University of Technology in 1992 and a bachelor in Applied Chemistry with honours from the Lions Eye Research institute. In the group of Traian Chirila he successfully obtained his PhD on the work of Poly(vinyl alcohol) as a Potential Vitreous Substitute. He broadens his experience within various research projects as a post-doctoral researcher. From 2005 to 2008 he was also a member of the group of Hugh Perry and working on Melt Electrospinning, Neuroimmunology and Experimental Spinal Cord Surgery. Since 2009, Paul Dalton has become adjunct Professor at the Queensland University of Technology and teaches Biofabrication, 3D Printing and Nanomedicine. In 2014 he moved as a Professor for Biofabrication, Neural Tissue Engineering and Polymer Processing to the JMU in Würzburg. In Würzburg he combines his experience from e.g. the production of an artificial cornea for clinical trials and uses his experience of combining biofabrication, experimental spinal cord surgery, advanced *in vitro* systems, tissue engineering and nanomaterials science.

Elena De Juan Pardo

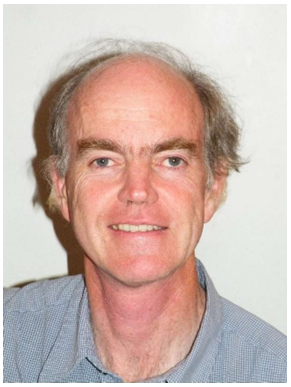
Queensland University of Technology, Brisbane

Topic

Mechanical Properties of Melt Electrowritten Scaffolds

Bio

Dr.-Ing. De-Juan-Pardo is a Senior Research Fellow and Deputy Director of the Centre in Regenerative Medicine at the Institute of Health and Biomedical Innovation (IHBI), Queensland University of Technology (QUT) (Brisbane, Australia). She graduated as a Materials Engineer from the University of Navarra (San Sebastian, Spain) in 2001. She completed her doctoral work at the Max-Planck-Institute for Plasma Physics (Garching b. Munich, Germany) and received her PhD from the Technical University of Munich in 2004. Later, she joined the University of California, Berkeley as a Postdoctoral Fellow to start building up her research capacity in bioengineering. Between 2008 and 2012 she established the Tissue Engineering and Biomaterials Group in CEIT (San Sebastian, Spain) and served as Director of the Master in Biomedical Engineering (University of Navarra, Spain). In 2013 she joined the Centre in Regenerative Medicine led by Prof. Hutmacher at IHBI to further expand her interdisciplinary research skills in the area of biofabrication. During her years at QUT, she has contributed to the development of melt electrowriting (MEW), a pioneering 3D printing technology that enables the production of highly controlled scaffolds for a variety of applications, including tissue engineering, regenerative medicine and cancer modelling. Dr.-Ing. De-Juan-Pardo has more than 40 publications, including articles in top journals such as Advanced Materials, Nature Protocols, PNAS and Biomaterials. She has secured more than one million euros in research funding as Chief Investigator and received multiple prestigious awards including the Spanish National Prize in Materials Engineering (3rd Place) in 2001, the Otto-Hahn-Medal of the Max-Planck Society in 2005 and the Stem Cells Young Investigator Award in 2012 (co-first author of winning article).



Brian Derby

University of Manchester

Topic

The Evolution of 3D Bioprinting

Bio

Brian Derby is Professor of Materials Science at the University of Manchester where he is Director of the Manchester Centre for Digital Fabrication. He organised, along with Doug Chrisey, the “First International Workshop on Bioprinting and Biopatterning” in September 2004 and was on the Founding Editorial Board of Biofabrication. He has worked in additive manufacturing and 3D printing since the 1990s with a particular focus on the use of inkjet printing technology. He graduated from the University of Cambridge with Bachelors, Masters and Ph.D. in Materials Science. Since then he worked in Grenoble, Cambridge (again), Oxford before his current appointment in Manchester. He is an Academician of the World Academy of Ceramics, Fellow of the Institute of Materials, Mining and Minerals (UK) and was awarded the Edward de Bono Medal for original Thinking and the Saatchi and Saatchi awards for World Changing Ideas in 2008.

Larisa Florea

Dublin City University

Topic

Direct Laser Writing by Two-Photon Polymerisation

Bio

Dr. Larisa Florea studied organic chemistry and chemical engineering at University "Politehnica" from Timisoara, Romania (B.Sc. Hons 2009). In 2009 she joined the Adaptive Sensors Group at Dublin City University where she earned her Ph.D. under the supervision of Prof. Dermot Diamond and Dr. Fernando Benito-Lopez. In 2011-2012, Larisa spent several months in Australia (University of Tasmania and University of Wollongong) as part of an extensive collaboration with The Australian Research Council (ARC) Centre of Excellence for Electromaterials Science (ACES) funded under the EU Marie Curie IRSES Program. Since 2013 she has worked as a postdoctoral researcher with Prof. Dermot Diamond in the INSIGHT Centre at Dublin City University. In 2015 she became Team Leader in smart materials and microfluidics. In 2018 Larisa was awarded a prestigious Irish Research Council Laureate grant that will enable her to establish an independent research career. Larisa's project aims to develop soft 3D micro-structures that exhibit biomimetic behaviour, such as programmed movement, uptake, transport of molecular cargo, and molecular sensing.

Aurélien Forget

Queensland University, Brisbane

Topic

Introduction to Hydrogels

Bio

Dr. Aurélien Forget is an early career researcher (less than 5yrs after PhD). He has obtained is Master of Science in Polymer Chemistry from the University Pierre et Marie Curie in Paris, France, in 2009. During his studies he gained an extensive international experience by working in various research laboratories. In 2007 at Hamilton College, (Clinton, New York, USA) through the Hamilton College Junior Year in France exchange program and at the Max Planck Institute for Colloid and Interface (Gölm, Germany), through the Erasmus exchange program. In 2008 he was invited for an internship at the University of Florida (Gainnesville, Florida, USA) through the US-National Science Fundation (NSF) founded Research Experience for Undergraduate (REU) program. For his master thesis, in 2009 he joined the Institute for Macromolecular Chemistry of the University of Freiburg (Freiburg, Germany) where Aurélien stayed to pursue his Doctoral studies. Aurélien was awarded his Ph. D. with ”*Summa Cum Laude*” (highest grade) at the University of Freiburg in 2014 with the thesis: "Synthetic Extracellular Matrix for Controlled Endothelial Cell Organization". Later in 2014 he was offered a postdoctoral associate position at the University of South Australia where he worked as part of the Collaborative Research Centre for Cell Therapy Manufacturing (CRC-CTM) where he was developing solutions for the transport and transplantation of pancreatic islets. Aurélien joined the laboratory of Ass. Prof. Tim Dargaville at the Queensland University of Technology in February 2017 as Associate Lecturer where he is currently working on hydrogels. Aurélien’s research focuses on developing novel materials and material processing techniques for biological and medical applications. His research interest is oriented toward developing novel systems to understand the interactions between cells and their environment. This involves developing synthetic biopolymers hydrogels, functional surfaces and technique to fabricate biointerphases such as 3D bioprinting and microfabrication. The development of these innovations is driven by Aurélien's passion for solving current and future health care challenges, specifically in the area of regenerative medicine.

Uwe Gbureck

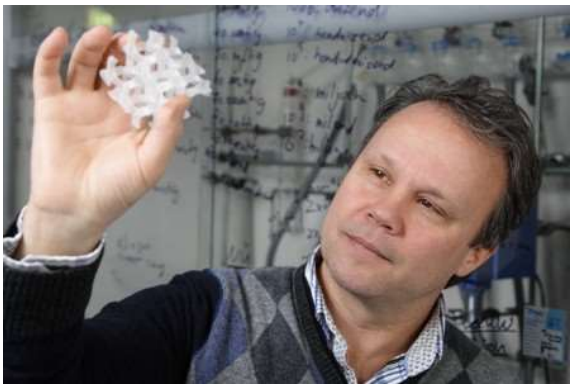
University of Würzburg

Topic

Inorganic 3D Printing

Bio

Uwe Gbureck is a professor in the Department of Functional Materials in Medicine and Dentistry, University of Würzburg. He earned a PhD degree in chemistry from the University of Würzburg in 1999. His research interests include the chemistry and material properties of mineral biocements based on calcium and magnesium phosphate chemistry, the use of such cement in rapid prototyping applications, as well as drug delivery systems based on inorganic structured materials.



Dirk Grijpma

University of Twente

Topic

Stereolithography

Bio

Prof. Dr. Dirk W. Grijpma is professor and head of the department of Biomaterials Science and Technology at the University of Twente. He also holds a part-time professorship in the Development and Clinical Application of Biodegradable Polymers at the University Medical Center Groningen. His expertise is in the synthesis, additive manufacturing, advanced processing and properties of (degradable) polymeric materials for use in medical devices, tissue engineering and in the delivery of relevant biologically active compounds. His research also includes the interaction of these materials and devices with cells and tissues.

He is editorial board member of Biomaterials, Acta Biomaterialia, Multifunctional Materials, the Journal for Applied Biomaterials and Biomechanics, the Journal of Orthopedic Translation and the Journal of Medical Materials and Technologies. He was elected Fellow Biomaterials Science and Engineering (FBSE) in 2008. Professor Grijpma is (co)author of more than 250 refereed scientific publications and is (co)inventor on 24 international patent applications.

Jürgen Groll

University of Würzburg

Topic

Fundamentals of 3D Bioprinting

Bio

"Prof. Jürgen Groll holds the chair for Functional Materials in Medicine and Dentistry at the University of Würzburg. His research interest comprises applied polymer chemistry for life sciences, biomimetic scaffolds, immunomodulation, nanobiotechnology, and biofabrication. Within biofabrication, he coordinates the large European integrated project HydroZONES that focuses on the printing of layered constructs for cartilage regeneration. Since 2014, he also holds the ERC consolidator grant Design2Heal that concerns the evaluation of design criteria for immunemodulatory scaffolds. Prof. Groll received his Ph.D. from the RWTH Aachen University with *summa cum laude* in 2005. From 2005 to 2009, he worked in industry in the field of functional coatings and biocomposite materials. In parallel, he built up a research group on polymeric biomaterials at the DWI Interactive Materials Research Institute in Aachen. He is board member of the international society for biofabrication and editorial board member of the journal Biofabrication. His work has been recognized by several awards such as the PhD thesis award of the German Society for Biomaterials in 2005, the Bayer Early Excellence in Science Award 2009, the Reimund-Stadler award of the Division of Macromolecular Chemistry of the German Chemical Society in 2010 and the Unilever Prize of the Polymer Networks Group in 2014." [Source: https://selectbiosciences.com/conferences/biographies.aspx?conf=bpeuro2016&speaker=934168]

Boris Holzapfel

University Hospital, Würzburg

Topic

3D Printed Implants

Bio

“Dr. Boris Holzapfel has authored and co-authored several national and international publications and also working as a reviewer for reputed professional journals. Dr. Boris Holzapfel is having an active association with different societies and academies around the world. Dr. Boris Holzapfel made his mark in the scientific community with the contributions and widely recognition from honourable subject experts around the world. Dr. Boris Holzapfel has received several awards for the contributions to the scientific community. Dr. Boris Holzapfel major research interest involves Orthopaedic Surgery, Biomedical Engineering, Musculoskeletal Oncology, Bone Tumours, Sarcoma, Bone Metastases, Hip and Knee Arthroplasty, Bone Tissue Engineering, Regenerative Medicine.” [Source: https://biography.omicsonline.org/australia/queensland-university-of-technology/boris-holzapfel-1598721]

Senentxu Lanceros-Mendez

Basque Center for Materials, Applications & Nanostructures

Topic

3D Printing in Context

Bio

S. Lanceros-Mendez graduated in physics at the University of the Basque Country, Leioa, Spain. He obtained his Ph.D. degree at the Institute of Physics of the Julius-Maximilians-Universität Würzburg, Germany. He was Research Scholar at Montana State University, Bozeman, MT, USA and visiting scientist at the, Pennsylvania State University, USA and University of Potsdam. He is Research Professor and Scientific Director at BCMaterials –Basque Center for Materials, Applications and Nanostructures, Derio, Spain and Associate Professor at the Physics Department of the University of Minho, Portugal (on leave). From 2012 to 2014 he was also Associate Researcher at the INL – International Iberian Nanotechnology Laboratory. His work is focused in the area of smart and multifunctional materials for sensors and actuators, energy and biomedical applications, with over 450 publications and 10 patents in the field.

Daniela Lössner

Barts Cancer Institute

Topic

3D Printing in Cancer Research

Bio

Daniela is a cell biologist and Reader in Bioengineering and Cancer at Barts Cancer Institute in London. She studied Biological Sciences and received her PhD from the Faculty of Chemistry at the Technical University of Munich in Germany. Her research interests are to understand the role of the extracellular and cellular microenvironment in modulating cancer progression and therapy response applying tissue-engineered technologies. Until February 2017, she was a Deputy Director in the Centre for Regenerative Medicine at Queensland University of Technology in Brisbane, Australia, leading the interdisciplinary 3D Cancer Models Team. In March 2017, she joined Queen Mary University of London to integrate patient-derived cells into these 3D models using the Cross-Institute Advanced Tissue Engineering (CREATE) biofabrication facility.

Robert Luxenhofer

University of Würzburg

Topic

3D Printing with Polyoxazolines

Bio

“Prof. Luxenhofer studied chemistry at the TU München and at the Sydney University. As a PhD student, also at the TU München and Postdoc (at the University of Nebraska Medical Center, Ohama, NE, USA and TU Dresden, Germany) he developed novel types of poylmerizations and laid the foundation to study the interaction of synthetic biomaterials and biological systems. The research interests of Prof. Luxenhofer are novel drug delivery systems for highly hydrophobic drugs as well as proteins and RNA/DNA. In particular, he is interested in structure/property relationships governing the interactions between the polymer and its cargo. Moreover, we develop novel polymers and polymerization methods as well as novel materials for the biofabrication and tissue engineering.”

[Source: http://www.matsyn.uni-wuerzburg.de/mitarbeiter/professoren/prof-dr-robert-luxenhofer/]

Vladimir Mironov

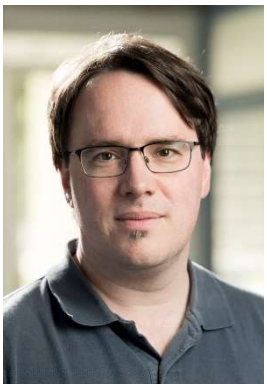
3D Bioprinting Solutions

Topic

The Future of 3D Bioprinting

Bio

Vladimir Mironov was born in Russia in 1954. Vladimir Mironov finished Ivanovo State Medical Institute in 1977 as a medical doctor. He got his PhD in Developmental Biology from Second Moscow Pirogov Medical Institute in 1980. He was trained by Prof. Peter Kaufmann at The Department of Anatomy RWTH in Aachen and Werner Risau's lab in Germany in Max Planck Institute for Psychiatry in Matinsried, Germany. He later worked at The Department of Anatomy and Regenerative Medicine and Advanced Tissue Biofabrication Center in The Medical University of South Carolina in Charleston, SC, USA and then at The Division of 3D Technologies of Renato Archer Institute for InformationTechnology at Campinas, SP, Brazil. Last 5 years he worked as a Chief Scientific Officer at 3D Bioprinting Solutions and Leading Scientist at Regenerative Medicine institute of Moscow Sechenov Medical University, Moscow, Russia. He is one of pioneer of 3D bioprinting technology. He already bioprinted a first functional and vascularised organ construct - a mouse thyroid gland.



Bastian Rapp

Karlsruhe Institute of Technology (NeptunLab)

Topic

3D Printing with Liquid Glass

Bio

"Bastian E. Rapp studied mechanical engineering at the University of Karlsruhe and finished his PhD at the same university in 2008 working on biosensors for biomedical diagnostics. He is a Principal Investigator and head of NeptunLab at the Institute of Microstructure Technology of Karlsruhe Institute of Technology. In 2017 he finished his "Habilitation" with the publication of a textbook on fluid dynamics in microfluidics. His research focuses on the development of novel materials, processes and applications in microsystem engineering, life sciences and biotechnology as well as instrumental and clinical analytics.

For his work he was awarded, among others, the *Edison Award* of the General Electric (GE) Foundation, the *REHAU award*, the *GMM award*, and the *Südwestmetallförderpreis*. His work has been published in the most important international journals including *Lab-on-a-Chip*, *Advanced Materials*, *Angewandte Chemie* and *Nature* and has been featured in national and international radio and print media including the *BBC*, the *New York Times* and the *Discovery Channel*."

[Source: https://www.neptunlab.org/index.php/bastian-e-rapp.html]

Dirk Schubert

University of Erlangen-Nürnberg

Topic

Introduction to Rheology

Bio

Dirk Schubert is Head of the Institute of Polymer Materials at the Friedrichs-Alexander-University Erlangen-Nürnberg. His main research interests are Polymer physics and processing, Polymer Composites, Fiber Spinning and Percolation. He studied Physics at the University of Würzburg where he graduated in 1992. Then he moved to the MPI for Polymer Science in Mainz. There he successfully obtained his PhD and worked as a postdoctoral researcher. After a year as a researcher at the GKSS Research Centre in Geesthacht he became the Head of Neutron Scattering Department. Besides the scientific career he also started a successful career in industry, first at the Freudenberg Research Services KG. Until 2010 he was the Director of Process Development at Freudenberg Vliesstoffe KG. During his stay at Freudenberg he also finished his Habilitation at the University of Kiel. One of the most recent research articles is entitled “Electrospun Polyhydroxybutyrate/Poly(ε-caprolactone)/Sol–Gel-Derived Silica Hybrid Scaffolds with Drug Releasing Function for Bone Tissue Engineering Applications” and was published in Applied Materials and Interfaces.

Georg Schwalme

SKZ-Kunststoffzentrum, Würzburg

Topic

Selective Laser Sintering

Bio

After studying electrical engineering, Georg Schwalme initially worked as a developer and then as a group leader and department manager in the R&D department of AEG Hausgeräte AG. His later responsibilities as plant manager of a vacuum cleaner factory were followed by assuming international responsibility also for the factories in Hungary and Sweden.

After moving to Bosch and Siemens Hausgeräte GmbH (BSH), he was responsible for three locations in Germany, Spain and Asia with a total of around 1,000 employees. Since 2008 Mr. Schwalme has been active in the plastics research and development of the SKZ. He is Business Unit Manager for injection molding and additive manufacturing and responsible for research, development and training activities.

Patrycja Szymczyk

University of Science and Technology, Wrocław

Topic

3D Metal Printing

Bio

"The scientific and research interests of Patrycja Szymczyk relate to the use of incremental technologies (SLM / DMLS, EBM, FDM, 3DP) for medical applications and include the development, manufacture and research of advanced biomedical objects, such as biomechanical functional structures (BSF) to support tissue regeneration, Type implants custom-made and matrices and excipients for a wide range of materials for the medical and pharmaceutical industries. She also specializes in the preparation and microscopic examination (SEM) of biological materials, nondestructive testing and functional analysis of biomedical structures. She is contributor in research and development projects, co-author of scientific publications in the field of incremental technologies, microbiological and materials research."

[Source: https://3dmeeting.pl /staff/ps_pl/]

Filippos Tourlomousis

Massachusetts Institute of Technology

Topic

Cell shape metrology using melt electrowriting

Bio

Filippos Tourlomousis studied mechanical engineering at University of Patras in Greece. He completed his Masters in experimental fluid dynamics at von Karman Institute for Fluid Dynamics in Belgium. At VKI, Filippos studied fire dynamics on small-scale explosion models using large scale particle image velocimetry techniques. Then, he moved to the US to complete his PhD at Stevens Institute of Technology, where he developed a machine learning-based metrology platform for the homogeneous expansion of mesenchymal stem cells on melt electrowritten scaffolds. Currently, he is working as a Post-Doctoral Associate at the MIT Center for Bits and Atoms, sister lab of the Media Lab and home of the thousand fab labs spread around the world. At CBA Filippos is working under the supervision of Prof. Neil Gershenfeld on rapid prototyping of machines for the processing of complex fluids. The project aims to accelerate the discovery of novel materials and make materials measurements accessible to the masses.

Felix Wunner

Queensland University of Technology, Brisbane

Topic

A Systems Engineering Approach to Melt Electro-writing

Bio

Felix is a mechanical engineer, strategic design thinker and entrepreneur, who is passionate to bring ideas successfully to reality.

During his studies at the TU Munich, NTU (Singapore), TU Berlin and QUT (Brisbane) he designed and developed services and devices. Besides academia, Felix filed patents, started three companies and launched products, which explored new markets, also via crowdfunding.

His Doctorate thesis in additive manufacturing for medical applications not only focused on better understanding the principles of electrowriting with molten polymers, but also aimed at translating the results of his core research to the real world – technically, yet also from an economic perspective.

Zhilian Yue

University of Wollongong

Topic

Biologically Derived Polymers as Bioinks

Bio

Zhilian Yue received her PhD in Polymer Chemistry in 2002 from Heriot-Watt University, UK, with Professor John McKenzie Grant Cowie. She is currently a senior research fellow at the Intelligent Polymer Research Institute, the ARC Centre of Excellence for Electromaterials Science, University of Wollongong, Australia. Her research interests are centred on developing polymer-based solutions to improve the therapeutic efficacy of tissue repair and regeneration. A long-term pursuit is to use biological principles to guide biomaterials design and development and to address critical issues in biomedical research. Her current focus involves integration of key technologies in bioprinting and tissue engineering and regenerative medicine, through development of multifunctional bioinks for cell printing.

Poster Abstracts

Development and characterization of a PLGA-HA composite material to fabricate 3D-printed scaffolds for bone tissue engineering

Joanna Babilotte[1], Vera Guduric[1], Reine Bareille[1], Damien Le Nihouannen[1], Thierry Cardinal[2], Manuel Gaudon[2], Jean-Christophe Fricain[1,3], Sylvain Catros[1,3]

P1

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Current bone tissue engineering strategies are based on porous biocompatible scaffolds seeded with tissue-specific cells. Improvement in rapid prototyping technology, such as 3D printing, allows fabrication of custom-made 3D scaffolds with high resolution. We have developed a new material, made of medical grade Poly(lactic-co-glycolic) acid (PLGA) mixed with hydroxyapatite nanoparticles (nHA), in the shape of a filament for 3D printing by Fused Deposition Modelling (FDM). PLA has shown its osteoconductive capacities in many studies, and the addition of glycolide can reduce the degradation rate. nHA was included to improve the bioactivity of the material for bone tissue engineering applications.

PLGA was mixed with 5% or 10% (w/w) nHA to fabricate a filament. Characterization of the materials were done by micro-raman spectroscopy and thermogravimetric analysis (TGA). Then, the materials were used to fabricate microporous membranes by FDM. The membrane topography was evaluated by Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). The membranes were seeded with human adipose-derived stem cells (ADSCs) or human bone marrow stem cells (HBMSCs). The cytotoxicity of the different biomaterials was assessed by MTT and Neutral Red tests on both cell types. Cell survival was evaluated by Live-Dead assay during 21 days of culture. Early osteoblastic differentiation was evaluated by qualitative expression of alkaline phosphatase (ALP).

The inclusion of nHA decreased the printing temperature relative to pure PLGA. Micro-Raman has shown the homogeneous distribution of HA particles with different size. The TGA has shown that we succeeded to obtain a composite material containing 9% or 4% of HA. SEM revealed that nHA particles were included regularly in the struts, resulting in a rough appearance. AFM showed an augmentation of the material roughness correlated to increased nHA concentration. Cytotoxic assays revealed no adverse effects on cells after 24h culture: the composite material was non-toxic and the cells could be seeded directly after sterilization without rinsing. Live-Dead assays have shown adhesion for both cell types as well as cell survival after 21 days of culture. ALP activity was higher using composite materials.

These experiments have shown that it was possible to fabricate a PLGA-HA composite biomaterial for 3D printing by FDM with favorable properties and relevant cellular response for bone tissues engineering applications.

Melt Electro Written 3D Migration Assays for Peripheral Nerve Regeneration

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P2

The nervous system is the most complex and least understood systems in the human body. When damaged, for example through peripheral nerve injuries due to trauma recovery is difficult to achieve. A surgeon must perform microsurgery on the severed or crushed nerve which often requires suitable lengths of bridging material when the nerves cannot be reconnected without tension. The golden standard up until now is to use an autograft nerve from elsewhere in the body. There is therefore a need for an off-the-shelf product that can be used to successfully bridge the nerve gap without performing a secondary surgery and creating another injury site.

For the presented work, we investigated the effect of different hydrogels to the migration of dorsal root ganglia cells (DRG). Melt electro writing (MEW) was used to 3D print in vitro migration assays with defined and intricate structures. The migration assays were melt-electro written on sPEG coated glass slides using polycaprolactone (PCL)***. In vitro*** migration assays were consists of a central cell depot and radially expanding matrix chambers. Within each chamber, a specific matrix formulation was dispensed. This work aimed to create 3D printed migration assay that will be used to systematically determine what matrices are likely to promote the greatest amount of regeneration ***in vivo*** to eventually use for peripheral nerve guides

Development of a 3D HTS Platform the Extend the Cell Adhesion Peptide Library in Biofabrication

P3

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As an alternative to natural extracellular matrix macromolecules, cell adhesion peptides have had a tremendous impact on the design of cell culture platforms, implants and wound dressings. However, only a handful of cell adhesion peptides (CAPs) have been utilized. The discrepancy in extracellular matrix composition strongly affects cell behaviour, so it is paramount to reproduce such differences in synthetic systems. This can be done by controlling matrix properties like stiffness and composition in vitro. Cell adhesion of a murine 3T3 cell line within a hydrogel matrix of different solid contents and different embedded CAPs was assessed. The CAPs used were derived from different ECM macromolecules to consider the complex environment of the natural cell environment. It could be found that CAPs, other than the in literature commonly used RGD, IKVAV, YIGSR promote cell adhesion to the hydrogel. In another experiment it could be demonstrated that hydrogel solid contents of over 25% still promote cell adhesion, when a RGD sequence was introduced to the system. However, this condition forces the cells into larger cell constructs, rather than building single cell-cell contacts and the influence of RGD got lower with higher matrix stiffness. Attempts to quantify the actual CAP content in the hydrogels were conducted using the bicinchoninic acid (BCA) and ninhydrin assay. Both assays were not viable for the use in the hydrogel system for side reactions occurred, which resulted either in a false positive colouring of the sample or dissolving of the sample. In a next step using a robotic liquid dispensing robot, it could be shown that cell spreading is not affected by handling of the cells with the robot. Furthermore, it was possible to deposit a larger number of hydrogels automatically using the system. Therefore, a high-throughput screening approach for the engineering of synthetic ECM with tailored physical and biochemical properties could be developed.

Topographical Patterning of Silk Fibroin Films using Melt Electrowriting for Ocular Surface Regeneration

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P4

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The silk protein, fibroin derived from the domesticated *Bombyx Mori* silkworm is a well-established biomaterial in the medical and tissue engineering field. Ultrathin free-standing silk fibroin membranes are viable cell carriers for ocular surface reconstruction. However, films were difficult to handle surgically. To resolve these issues, silk fibroin membranes were mechanically reinforced by incorporating poly(ε-caprolactone) (PCL) frameworks printed by melt electrowriting. Topography and suture compatibility of reinforced membranes with PCL pore sizes coded as 100×100 µm^2, 200×200 µm^2 and 300×300 µm^2 were analysed and assessed (Figure 1).

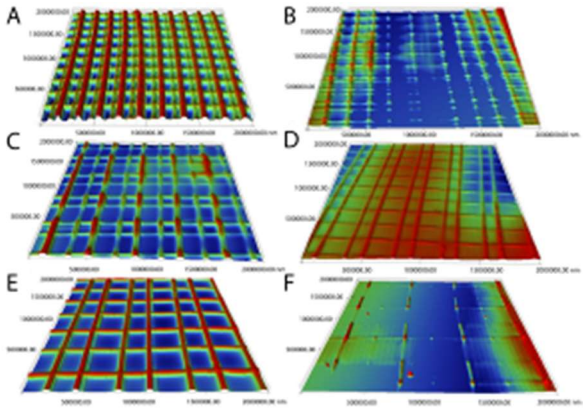

Figure 1 Stylus profiler 3D map scans of unseeded SF-PCL membranes of 100 µm (A,B), 200 µm (C, D), 300 µm (E,F) coded pore sizes for top (A, C, E) and bottom (B, D, F) surfaces.

Optimisations included O_2 plasma treatment (pt) of PCL fibres and increased casting volumes of silk fibroin solution to improve silk fibroin-PCL adhesion. Plasma treatment decreased presence of fractures and increasing the casting volume rid of abrasions seen on fibre junctions as seen in Figure 2.

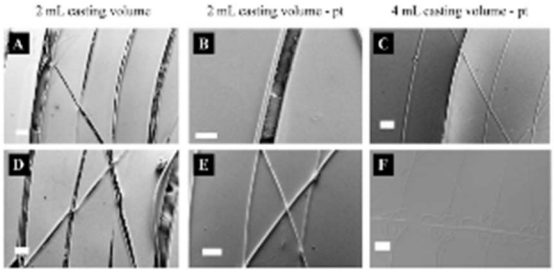

Figure 2 SEM images of membranes comparing differing casting volumes of 2 mL (A, B, D, E) or 4mL (C, F) SF solution and plasma treatment of PCL (B,C, E, F) (scale bars = 50 µm).

All silk fibroin-PCL substrates with various PCL pore sizes were comparable for suture tests yet notably more mechanically robust than silk fibroin alone.

Figure 3 Porcine cadaver eyes sutured with T100, T200 and T300 membranes of varying pore sizes (100, 200 and 300 µm^2 pore sizes respectively).

Cell morphology of primary rabbit corneal epithelial (RCE) cells demonstrated migratory behavior observed in mature limbal cells (Figure 4 & 5). The comparison of pores with areas of ca. 250 µm^2 versus ca. 330 µm^2 showed statistical significance in cell viability. Cells appeared to migrate along PCL frameworks, however this remained inconclusive for smaller pore areas (ca. 120 µm^2).

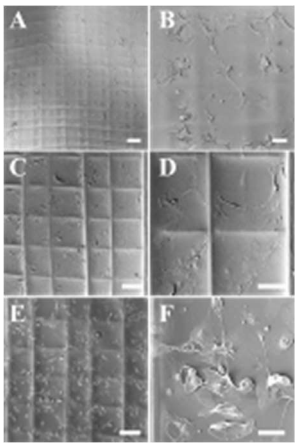

Figure 4 SEM images of primary RCE cells on SF-PCL membranes of 100 µm^2, 200 µm^2 and 300 µm^2 programmed pore sizes. (scale bars = A: 200 µm; B-D: 100 µm: E: 200 µm; F: 50 µm)

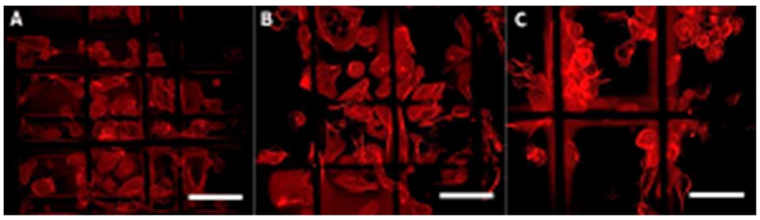

Figure 5 Primary RCE cells stained with phalloidin on SF-PCL membranes with 100 µm^2, 200 µm^2 and 300 µm^2 programmed pore sizes (scale bars: 200 µm).

These initial investigations have shown that PCL frameworks provides an alternative approach to the topographical patterning and mechanical reinforcement of the silk fibroin membrane, advancing its potential as a corneal epithelial cell carrier.

3D Metal Printing at the Microscale: Copper and Beyond

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P5

Today, the fabrication of tailored metal layers, patterns and structures is a topic of growing interest [1]. Applications of these custom-made designs can be found in various fields like optics, (bio)sensing, electronics and microelectromechanical systems (MEMS). Where traditional fabrication methods, such as stereolithography, are often time consuming and limited to 2D arrangements, additive manufacturing (AM) allows for the fabrication of structures without geometrical constraints. So far, however, solid AM methods for the purpose of manufacturing metal structures have only been established at the macro scale. The limitation of these AM techniques, such as the metal powder particle melting process, is their limited resolution, which is inadequate for (sub)micron scaled manufacturing [2].

Here we report the use of the Fluid Force Microscope (FluidFM), a technique enabling voxel by voxel printing of metal structures with sub-micron resolution [3]. Each voxel is printed by confined electroplating under the apex of the force-controlled nanopipette, and all subsequent voxels are deposited similarly in an automated, layer-by-layer fashion due to the system's integrated force-feedback. With the FluidFM we have successfully demonstrated the one-step, mask-free microprinting of a wide variety of pure 3D copper geometries.

To extend the range of applications for our 3D printed structures, we currently examine the electroplating of other metals such as gold and platinum with the FluidFM technology. Besides printing different metals, we are also interested in investigating the possibility of multi-material printing at the micron scale.

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Fabrication of Sinusoidal-like Scaffolds for Tendon Tissue Engineering Applications

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P6

Introduction: Tendon injuries are a source of significant morbidity to patients. Melt electrospinning writing (MEW) is used to produce defined fiber-based scaffolds where shape, fiber diameter and layer-by-layer stacking can be controlled to micron-scale printing resolutions [1]. Native tendon, which has a collagen extracellular matrix, has a highly organized "crimped" ultrastructure, and this is reflected in the mechanical properties of this tissue. Here we describe the direct-writing of "sinusoidal" scaffolds for tendon tissue engineering. Tendon cells (tenocytes) are mechanoresponsive [2] and we used a subtype of them, tendon stem/progenitor cells (TSPCs), which are important for tendon development and repair [3].

Materials and methods: A custom-made MEW device was used to print medical-grade polycaprolactone melt. The G-code for the collector movement allowed an oscillatory moving pattern. Straight fiber scaffolds were also produced as controls. Characterization of the scaffolds was performed by scanning electron microscopy and mechanical testing. TSPCs were seeded with a density of $3x10^5$ cells per scaffold inside a 12-well cell culture plate. Live/dead staining was performed at days 1, 3 and 7.

Results: The sinusoidal fibers had a diameter of 15 µm and a crimp angle of 25-35°. Straight scaffolds had the same fiber diameter. The stress/strain curve showed a toe region for sinusoidal scaffolds compared to straight ones [Fig. 1]. Live/dead staining showed attachment of TSPCs on day 1 and proliferation till day 7. The cells were generally aligned with the overall direction of the fibers in both scaffold types [Fig 2].

Conclusion: It was possible to print sinusoidal MEW scaffolds with fiber diameter approximately equivalent to the primary collagen bundle in a tendon. The "toe region" in the stress/strain curve of sinusoidal scaffolds is of similar shape to that of native tendon while TSPCs could attach and proliferate and align along the direction of the fibers. Further exploration of the effects of crimped fibers on TSPCs is planned by checking gene expression of tenogenic markers.

3D hybrid printed structures for auricular cartilage regeneration

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P7

Three-dimensional (3D) hybrid printing is a promising technique to overcome the limitations of current autologous reconstruction technique of the external ear. The ideal 3D-printed hybrid constructs should provide the mechanical properties required for the human ear and allow enough diffusion to provide nutrients and oxygen for the encapsulated cells in the hydrogel. In addition, the polymeric framework needs to protect the cells from skin contraction or external influences while it matures.
The hybrid printing strategy in this work includes two main materials, the supporting material and the hydrogel. As supporting material polycaprolactone (PCL) is used to deliver the structure similar to the mechanical characteristics of the human ear. The hydrogel ink is a combination of gelatin methacrylate (GelMa) and hyaluronic acid with methacrylate (HAMa) (later called: GelMa-HAMa). GelMa-HAMa is expected to provide the biological environment, as well as to facilitate cell growth and differentiation of the cells. In addition, depending on the geometry of the construct a sacrificial material is needed to achieve an optimal shape of the printed structure. In this work Pluronic F127 is used as sacrificial material.
The combination of different materials opens up the possibilities to design scaffolds for specific applications with matching or tailored properties. For the regeneration of the auricular cartilage, an ear shaped scaffold with a structural support layer is needed. The structural support needs to be mechanically robust but also cell friendly.
In this regard, an advanced 3D hybrid printing method with three different materials is presented in this work. The printing conditions and parameters of the materials with the extrusion-based 3D BIOPLOTTER (envisionTEC, Germany) were established and optimized. The hybrid scaffolds were found to be suitable to mimic the mechanical properties of the six different parts of the native auricular cartilage by varying the pattern design. It was possible to get a range of compression moduli from 2.5 to 10.0 MPa similar to the native ear. In addition, the influence of the pattern design on the bending behavior was studied. The stiffness and the bending behavior of the hybrid scaffolds was mainly given though the PCL and the environment for the cells is provided with the hydrogel gelMa-HAMa, which is printed in-between the PCL strands.

Measuring thermal degradation during melt electrospinning writing

Christoph Böhm, Andrei Hrynevich, Gernot Hochleitner, Jürgen Groll, Jörg Teßmar, Paul D. Dalton

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P8

Introduction: Solution electrospun scaffolds are widely used to investigate cell behaviour[1]. One disadvantage of the process is that organic solvents (often cytotoxic) are often required. A non-solvent alternative is called "Melt Electrospinning Writing" (MEW) that uses polymer melts instead of solutions to produce 3D scaffolds with improved precision of fibre placement. One limitation with MEW is the requirement of low flow rates while elevated temperatures can result in degradation of the polymer. This investigation uses specific printing conditions to allow 1) monitoring of degradation and 2) predicting of the degradation when new polymers are processed via MEW.

Materials and methods: Polymers (PCL and PLGA) are heated in a glass syringe and loaded into a custom-built MEW printer. The syringe is purged with nitrogen gas for 15 min to prevent oxidation or hydrolysis during heating. The melt is driven out to the spinneret by nitrogen pressure, and a high voltage applied to the spinneret. An electrified molten jet is direct-written over a collector, first stabilized and then as arrays on a microscope cover slip, that were divided into 9 blocks with 4 arrays each.

Results: MEW could be performed in two modes – linear or non-linear, depending on the collector speed[2]. When the speed of the collector matches or is above the speed of the jet, straight lines result. For collector speeds slower than the jet, non-linear fibres with patterns are generated. The speed where the collector and jet are equal is referred to as the "Critical Translational Speed" (CTS). Monitoring the shape of the fibre deposited around the CTS allows observation of thermal degradation of the polymer over time.

Conclusion: Observing shifts in the CTS allows investigation of thermal degradation of molten polymers. This method of monitoring the CTS and resulting deposition patterns enables early determination of thermal degradation under actual printing conditions. Future research is required to determine whether it is the generation of charged species and/or viscosity reduction that results in changes in jet behaviour with time.

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Hydrogel-coating of a Polymer-Film in a customized 3D-printed reactor via SIPGP

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In tissue engineering sometimes materials have the wanted fuctionality, but not the needed biological or mechanical properties. An elegant way to solve this is to coat them with suitable fuctional materials like hydrogels. So here a PVDF-terpolymer-film was coated with a hydrogel by covalent bonds to achieve a surface modification of the polymer. The hydrogel consists of the monomers HEMA (2-hydroxyethylmethacrylate) and MEDSAH ([2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammoniumhydroxide), which are both water soluble. The coating was achieved using self-initiated photografting and photopolymerisation (SIPGP). This method allows the omission of auxiliary photoinitiators, if adequate surfaces and monomers are used. These two facts make this procedure ideally suited for tissue engineering or medical applications. In order to achieve a consistent and controllable coating the reaction needs to be done under argon and with a consant flow of the monomer-solution. This circumstances require a customized reactor, that can easily be 3D-printed. Here the reactor was designed using blender and printed with a DLP-printer (Autodesk Ember). The monomer-flow during the reaction was attained by attaching a syringe-pump to the reactor while irradiating it with a UV-Lamp. The successful modification of the surface was confirmed through Raman-, as well as IR-Spectra, that showed distinct peaks of the hydrogel. Also SEM-pictures were made, that showed a modification of the surface. This modification lead to a change in the hydrophobic behaviour of the pure polymer-film to a hydrophilc one of the coated film, which was confirmed by contact angle measurements with water. The biological propertys are also expected to be improved by the hydrogel-coating. In addition the use of the composite as a moisture-triggered actuator could be shown.

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PHARMAZIE

Design and 3D Printing of Multimodal, Multiphasic Scaffolds

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Dept. of Functional Materials in Medicine and Dentistry, University Hospital Würzburg, Germany

P10

Introduction: Melt electrowriting (MEW) is a distinct additive manufacturing process that electrically sustains a falling fluid from breaking up at very low flow rates (µL/hr) [1]. It has been used for different biomedical applications including T-cell therapy [2], tissue engineering, regenerative medicine, and cancer research [3]. From one perspective, MEW can be considered a hybrid between melt micro-extrusion and electrospinning, however the fiber dimensions and placement control, respectively, are greatly improved. MEW has been performed so far with poly (ε-caprolactone) (PCL), polypropylene, fugitive inks and photocurable polymers [4].

Methods: A custom-built MEW printer was used in this study. Described elsewhere [5], this MEW printer has a digitally controlled air-pressure supply, connected to a disposable syringe containing medical-grade PCL, heated to 70-90°C. The PCL melt is extruded through a flat-tipped nozzle that has between 4-7 kV voltage applied. As shown in Fig. 1, the MEW printing head is kept static between 3-6 mm above a stainless-steel collector, which is then translated to enable direct-writing. Fibres printed immediately after the changes in the air pressure were separated by off-sample printing of a sham construct. Calibration curves for both air pressure and speed were done and direct-writing of multi-phasic and multi-modal scaffolds performed.

Results: The PCL fibre diameter was controllable with 1) air pressure with longer switching times (minutes) and 2) collector speed with fast switching times (seconds or less). As a result, we were able to produce a multi-phasic scaffold where each part contains different with different fiber densities. In this instance, we could accurately produce trimodal scaffolds in a single printing step, that contain different dimensional elements to both provide a high surface area for cell attachment as well as an improved handling for a tissue engineering scaffold.

The electrostatic writing of polymer melts produces a defined electrified jet that can be direct-written. Since the flow rate and collector speed to the spinneret have the most significant impact on fiber diameter, we developed an air pressure and writing speed control system to rapidly influence the electrified molten jet so that fiber diameters can be significantly altered by over one magnitude during the direct writing process[6]. This has implications in the fabrication and design for tissue engineering scaffolds, filters, textiles, energy and electronic applications.

Conclusions: MEW is a capable additive manufacturing technology that can fabricate porous materials using a spectrum of different diameter fibres. Using both air pressure and collector speed control, the fibres that constitute the scaffold can be manufactured with over a magnitude difference in diameter, using the same nozzle.

Acknowledgements:
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A Patient-Derived Bioengineered Model to Investigate Stroma-Epithelium Interactions in Prostatic Diseases

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Prostate cancer is the most common type of cancer in men. Therapies are often successful but comprehension of the disease and its mechanisms is still not very advanced. Treatment investigations are focusing on the metastatic stage whereas early stage tumor development is often neglected. Prediction tools in prostate cancer diagnosis often fail due to a lack of accurate models and therefore an incomplete understanding of the exact mechanisms involved in the development of the early stage disease as well as tumor progression and invasion. In this study we develop a patient-derived, three-dimensional, bioengineered prostatic model to examine interactions between the epithelium and surrounding connective tissue and therefore gain a better understanding of the role of the microenvironment already during the early phase of disease development. A reproducible way of manufacturing the micro tissues, mimicking the native architecture of a prostate, was established. Formation of a basement membrane-like structure, representing a key component in cancer progression, was proven and functionality validated by analyzing expressed proteins, associated with basement membrane degradation, after adding highly invasive prostate cancer cells to the model.

Ultra-soft Matrix Composites for 3D Neuroglia *in vitro* Research

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P12

The nervous tissue is considered one of the softest tissues of the human body. In order to study the native brain as well as neurological diseases, such as brain tumors, it is crucial to create models, which mimic the mechanical and biological properties of the brain[1]. *In vitro* cell culture systems have been an indispensable tool for clinical research. However, cells grow within a complex 3-dimensional (3D) environment *in vivo* and are associated with an extracellular matrix (ECM), which cannot be mimicked by conventional 2D monolayer cultures. The ECM, [e.g. collagen, hyaluronic acid (HA), fibronectin (FN)] is a pivotal component of cell signalling and controls neuronal features[2]. Additionally, the tumor ECM dictates tumor growth, migration, invasion and maintenance of tumor cell differentiation. Hence, the development of 3D tissue culture models is crucial to the understanding of the complex behavior of the brain. However, it is a challenge to establish a 3D model possessing the properties of the brain, as suitable hydrogels are often instable.

Here, we present a 3D model, which consists of fibre-reinforced ultrasoft hydrogels, simulating an artificial extracellular matrix with a stiffness of 100-300 Pa and elasticity comparable to human nervous tissue. Matrigel™ was strengthened with highly organized Poly ε-Caprolacton (PCL) – fibres, that were 3D-printed with a technique termed as melt-electrospinning-writing (MEW)[3]. The mechanical properties of these scaffold / matrix composites increase synergistically, compared to either the scaffold or matrix individually.

In order to show, that these models are capable of studying brain function and synaptic transmission, we cultured murine neurons and astrocytes on these fibre-reinforced ultrasoft 3D-matrix. 3D electrophysiological measurements were established, using a mouse fibroblast cell line and will be adapted on neurons in the future. Furthermore, we successfully cultured U87-cells, a glioblastoma cell line, to study changes in cell behavior in the tumor microenvironment (TME). These ultrasoft composites provide a robust model to obtain further understanding of cell-matrix interactions in the native brain as well as in the TME.

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Light Activated Nitrile Imine Mediated Reaction Pathways for the Synthesis of Bioinks

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P13

Light-activated crosslinking of hydrogels is a widely used technique in bioprinting to achieve spatio- and temporal-control of printed structures. Although there are numerous techniques involving different chemistries to achieve this, these methods all require the addition of small molecule photoinitiators. Photoinitiators have been shown to be cytotoxic at certain concentrations and are less suitable for crosslinking in the presence of cells for bioink applications. The focus of this thesis was to develop and characterise a hydrogel system that could be photochemically crosslinked without adding a photoinitiator by functionalising polymers with tetrazole 'click' chemistry. A simple method for functionalising gelatin with a tetrazole moiety was developed and characterised via ^{1}H and diffusion nuclear magnetic resonance (NMR) spectroscopy, rheology and x-ray photoelectron spectroscopy (XPS). Photochemical crosslinking of this material was studied alone and as a mixture with other polymer components. Fluorescence was used to follow the crosslinking kinetically, while it was possible through colloidal probe measurements on an atomic force microscope (AFM) to show that irradiation caused an increase in the stiffness of the material both as a homopolymer and in the presence of polymers with suitable reactive moieties. This work provides a basis for the use of tetrazole chemistry in the field of biofabrication as an initiator free approach to crosslinking.

Drug Loaded Microparticles as a Potential Treatment for Chronic Urinary Tract Infection

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P14

Urinary tract infections (UTI) are a worldwide medical healthcare issue, affecting approximately 1 in 2 women will develop a UTI at least once in their life and 1 in 2000 men will develop one every year. In the US alone, 400,000 hospitalisations for UTIs had an associated $2.8 billion USD in healthcare cost. A majority of these are acute infections which are resolved, however a subset of these become develop into chronic infections which stay with the patient often for life. There are a number of reasons for the persistence of these infections which have recently been found, one of them being the invasion of infection causing bacteria into the host cells where they are protected from the immune system and antibiotic treatments. In this work, the authors proposed to prepare biodegradable drug loaded microparticles designed to be taken up by cells and to release the drug intracellularly in order to kill the bacteria. Microparticles with a mean diameter of 2.5 µm and a PDI of 0.2 were produced using electrohydrodynamic atomization. Particles were subject to 20 kGy of gamma radiation to assess feasibility of end point sterilization. FTIR and Raman analysis reveal no change in spectra before and after gamma radiation indicating no new chemical groups were formed. Particles could kill as effectively or with similar effectiveness when compared with the drug alone when tested against some common UTI causing bacteria: *E. Faecalis, Citrobacter Koseri, Staphylococcus Saprophyticus, E. Coli and Enterobacter.* Cell uptake in 2D cell cultures and 3D human organoids were confirmed by loading the particles with a fluorescent dye. The drug loaded particles co-cultured with organoids deliberately infected with *E. Faecalis* and were able to more effectively reduce intracellular bacterial load when compared with drug in solution. These drug-loaded microparticles present a promising alternative to current chronic UTI treatments.

3D Printing of Hydrophilic Polymers via Melt Electrowriting for the Fabrication of Microperiodic Hydrogel Scaffolds

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P15

3D-printing of hydrogel architectures combining a high structural integrity and a micrometer resolution is inherently difficult.[1] However hydrogel fibers with a diameter below 100 micrometer would be very beneficial for cell culture or as potential implants as they compromise fibers with large aspect ratios and very low stiffness. Such systems could be especially favorable for mimicking soft tissue environments like nerve or liver.[2] Melt electrowriting (MEW) is an emerging additive manufacturing technique capable of depositing very defined fibers with diameters even below 1 micrometer and therefore an excellent choice for the production of such structures.[3]

Here we report about the preparation and characterization of a poly(oxazin) (POzi) based polymeric material, which can be processed via MEW and through subsequent immersion into water establishes microperiodic hydrogel architectures. POzis are functionalized with furan and maleimide units allowing a thermally reversible crosslinking based on the Diels-Alder-reaction. The Diels-Alder-equilibrium enables the liquefaction and therefore the melt-processing of the material via heating to temperatures above 100°C. Upon cooling to room temperature, a chemically cross-linked network is established and the material can be swollen in water. The polymeric material presented here is characterized via DSC, Rheology and MEW processing performance.

The prepared scaffolds are soft and show no signs of structural disintegration upon incubation in water or PBS for several weeks. Therefore, short term applications as highly hydrophilic support structures for cell tests are envisioned.

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Optimization of 3D Printed Hydrogels for Ligament Tissue Engineering

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P16

We here reported on a tissue engineered Anterior Cruciate Ligament (ACL) scaffolds fabricated using 3D bioprinting technology. The aim of this *in vitro* study was to optimize the printing parameters for maximum cell viability, determinate cellular response and characterize mechanical properties of materials. Human ACL cells were used as constituent cells and mixture of gelatin, fibrinogen and hyaluronic acid were used as cell-laden hydrogel. Cell localization and proliferation were investigated to study cell functions and tissue formation process in 3D structures.

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Wet Electrospun Alginate/Gelatin Hydrogel Nanofibers for Three-dimensional Cell Culture

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P17

Convergence of biological and biofabrication approaches is necessary to progress new biomaterials promoting three-dimensional (3D) cell growth and maturation towards tissue regeneration and integration. The unavailability of donors and transplants increases the need for tissue engineering and regenerative medicine. Here, we have developed a novel approach to fabricate 3D macroporous, alginate/gelatin hydrogel nanofibers (Alg/GelF-MA) which provide superior cell adhesion, motility, proliferation and maturation. The nanofibers were fabricated using wet electrospinning. Electrospinning is a versatile technique used in the fabrication of nanofibers in the field of tissue engineering, regenerative medicine, drug delivery, etc. We validated that the fabricated Alg/GelF-MA nanofibers are non-toxic and biocompatible through both visualization and quantification. The cytotoxicity was found to be 8.85% $\pm$ 4.5%, when evaluated on hEGFP-MSCs, which makes them compatible for cellular studies. Furthermore, we demonstrated that the Alg/GelF-MA nanofibers supported 3D cell adhesion and proliferation of mesenchymal stem cells over 5 weeks and supported the maturation of human iPSC-derived ventricular cardiomyocytes, which significantly outperform cell encapsulated bulk GelF-MA hydrogel. The work provides an insight for rational design and development of 3D cell culture matrix for advancement of stem cell therapy and tissue regeneration.

Renal tubular- and vascular basement membranes and their mimicry in engineering vascularized kidney tubules

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The high prevalence of chronic kidney disease leads to an increased need for renal replacement therapies. While there simply are not enough donor organs available for transplantation, we ought to seek for other therapeutic avenues as current dialysis modalities are insufficient. The field of regenerative medicine and whole organ engineering is emerging, and researchers are looking for innovative ways to create (part of) a functional new organ. To biofabricate a kidney or its functional units, we need to understand and learn from physiology to be able to mimic the specific tissue properties. Here, we provide an overview of the knowledge on tubular and vascular basement membranes' biochemical components and biophysical properties, and highlight the major differences between the two basement membranes. Furthermore, we provide an overview of current trends in membrane technology for developing renal replacement therapies and to stimulate kidney regeneration.

Design of 3D-printed antibacterial membranes

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P19

Due to the increasing public health awareness of the pathogenic effects caused by microorganisms, there is a growing need for antibacterial materials in a wide range of areas like medical devices, health care and dental surgery equipments [1]. Electrospinning is a powerful technique using high electric forces between the polymer melt contained in a syringe and a target to produce 3D fibrous structures with diameters in the submicron and nanometre range. Nanofibrous membranes produced by electrospinning offer unique capabilites to control pore size and have potential for clinical translation if the biological efficacy of the membrane can be improved over existing gold standards [2].
Our work investigates the electrospinning process to create an antibacterial membrane for application in dental surgeries. For this aim we focus on the minimization of the pore size of the 3D-printed membrane by varying the process parameters such as temperature, pressure and collector speed to create bacteria-tightness while ensuring oxygen transport (Figure 1).

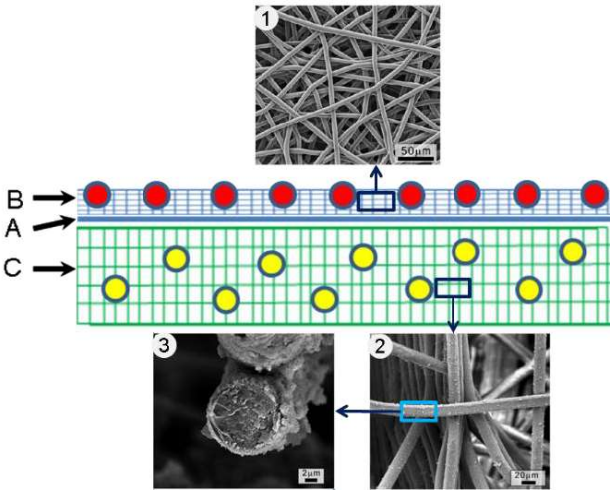

Figure 1. Schematic presentation of the bacteria-tight membrane. (A) Bacteria-tight core of the membrane. (B) Fine pored surface with anti-bacterial drug-delivery. (C) Coarsely porous under surface which supports cell migration.

Additionally, melt electrowriting will be used to create a fine pored surface with anti-bacterial drug delivery and a coarsely porous under surface to support cell growth from the bone.

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Design of anisotropic biomimetic scaffolds for patient-specific heart valve tissue engineering by melt electrospinning writing

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P20

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Valvular heart disease caused by stenosis, regurgitation or congenital defects are the third leading contributor to cardiovascular disease affecting more than five million people in the US annually. Tissue Engineered Heart Valves (TEHVs) have the potential to replace synthetic and non-bioactive prosthetics, which are incapable of supporting tissue remodelling and regeneration. In addition, TEHVs lack the mechanical properties necessary for physiological loading from systemic blood circulation. Engineered heart valves should exhibit anisotropic behaviour capable of withstanding loading while providing the physiochemical properties required for cell growth and tissue regeneration. For this purpose, biologically inspired electro-spun fibres were designed to mimic the wavy-like orientation of collagen fibres apparent in the Fibrosa and Ventricularis layer recapitulating the composition, dimensions and mechanical properties of the native valve while providing a biomimetic structure for extracellular matrix (ECM) deposition. Leveraging the capabilities of Melt Electrospinning Writing (MEW), medical grade poly ε-caprolactone (mPCL) fibers were deposited in predefined helical patterns with various radius, pore-size and layer number displaying the J shaped stress-strain curve and anisotropic mechanical characteristics of a native leaflet tissue. Moreover, tubular MEW was incorporated to fabricate the aortic root including the Sinuses of Valsalva based on physiological dimensions of healthy aortic valves. This study illustrates the potential of MEW for the fabrication of mechanically viable biomimetic scaffolds for patient-specific heart valve tissue engineering.

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