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Best osseointegrative surface characteristics of PEEK implants due to an evolutionary surface functionalization technique MBT (Mimicking Bone Technology)

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Introduction. While implant materials such as polymers (PEEK) are known for their good mechanical characteristics, they are also known for being bio-inert. Cells do not adhere properly to these materials. As a result, surgeons observe patients' pain and inflammatory reactions after surgery. Adverse effects even include implant loosening and expensive and painful re-operations cannot be avoided. To enhance the biological performance of PEEK implants, these materials are often mixed with HA (invibio) or coated with Titanium (Ti). But the high risk for patients with these kinds of Ti-PEEK composites are abrasion and delamination of Ti-nanoparticels, as Ti and TiO_2 is suspected to be toxic and carcinogenic.

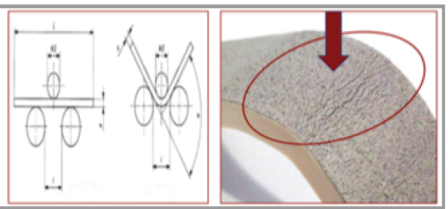
In the case of medical implants and prostheses, wear debris and ions release produced due to the loss of material by bio-tribocorrosion of implant surfaces have been related to tissue inflammatory reactions [3-5,6]. The presence of metallic ions and particles in human tissues induces the activation of macrophages, neutrophils, and T-lymphocytes with elevation of cytokines and metallic proteinases that can promote bone resorption [7–10]. Coalescence of particles of all classes (including titanium particles) originating from implants are often seen in the vesicles of macrophage cytoplasm in the liver, spleen, and para-aortic lymph nodes [10–19].

Titanium particles found in the lymph nodes ranged from 0.1 µm up to 50 µm, while in the liver and spleen the particles ranged from 10 µm [11]. An association between ultrafine TiO_2 (UF-TiO_2) (<100 nm in diameter) particles and adverse biologic effects have been reported in the literature [2,3]. Garabrant et al. [2] reported that 50 % of titanium metal production workers exposed to TiO_2particles suffered from respiratory symptoms, followed by injury of pulmonary function [20]. In agreement with previous studies in rats [12,15,16], recent studies in cultured human cells have also shown genotoxicity and cytotoxicity effects of UF-$TiO_2$1.

These scientific publications and the results presented herein led the authors consider the possible biological adverse effects of TiO_2 particles (<100 nm in diameter) produced during bio-tribocorrosion mechanisms of Titanium or Titanium coatings in the human body. To avoid risks for the patients associated with the use of Titanium or Titanium composites the authors developed and analyzed a new surface modification technique called Mimicking Bone Technology (MBT) invented to add best osseointegrative characteristics to pure PEEK surfaces. This MBT technology is patented / patent pending worldwide.

Titanium Plasma Spray Coating: High Risk of Wear Debris

EN ISO 7438 bending test of plasma-spray-coated surfaces clearly shows cracks in the coating layer. Delamination and abrasion may be a problem.



Pic. 1: Titanium coated PEEK surfaces tested byUniversity of Constance.

MBT Technology: Unique Surface Modification for PEEK Implants

The surface modification technique presented in this paper is not a coating technique but an evolutionary bio-chemically covalently joined surface functionalization resulting in unique, bone-identic and mineralized PEEKMBTimplant surfaces eliminating the risks of abrasion, wear debris and TiO_2 diffusion.

As the MBT surface modification is designed on a biomimetic basis, it includes the most advantageous properties of surface topography, surface chemistry and physicochemical parameters and combines it with state-of the art chemical strategies for the improvement of the longevity of the implant within the host.

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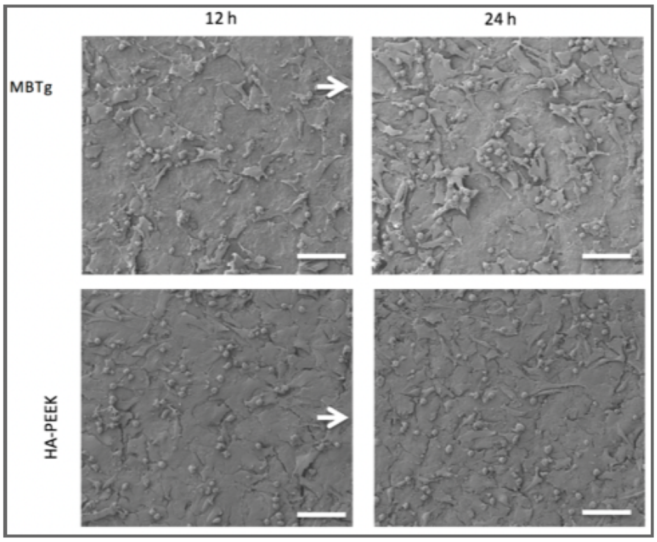
Therefore, from the point of view of inorganic surface modifications, implant surface designs and surface topographies should also incorporate all the relevant scales that interact with the surrounding cells. Also, it has been suggested that only a very specific surface topography with a roughness value between 1 and 1.5 µm provides an optimal surface for bone integration [9]. stimOS' engineered PEEKMBTsurface meets this range.

Material and methods. To demonstrate the superior performance of PEEK-MBT surfaces, in vitro cell tests and in vivo animal models have been developed and used to compare the characteristics of various implant surfaces, such as PEEK, HA enhanced PEEK (invibio), PEEK-MBT (stimOS) and Titanium.

Results. MBT surface modifications are process-validated technologies. The technology has been subject of statistically significant comparative in-vitro cell tests performed by the faculty of biology (University Constance) showing superior results regarding cell-adhesion, cell viability and cell proliferation compared to PEEK, Titanium and HA-enhanced PEEK materials. PEEK-MBT surface turned out to be the most suitable candidate for healing into the bone tissue among all tested materials due to high osteoblast proliferation and cell adhesion, and due to the most intensive formation of mineralized bone nodules (follow up 12h / 24h).



Pic 2: HA enhanced PEEK (invibio) material surface compared with PEEK-MBT surface (stimOS). Superior formation of mineralized bone nodules on stimOS PEEK-MBT surface.

To confirm the outstanding results achieved in in-vitro cell tests, an animal model was conducted - together with the University of Zurich and Charité Berlin - to demonstrate that stimOS MBT implant surface modification has evolutionary unique characteristics designed to support early bone formation and proper implant anchorage.

The animal model proofs that stimOS PEEK-MBT materials can be described as biocompatible, cell-attractive, osseointegrative and can be associated with anti-inflammatory material characteristics.

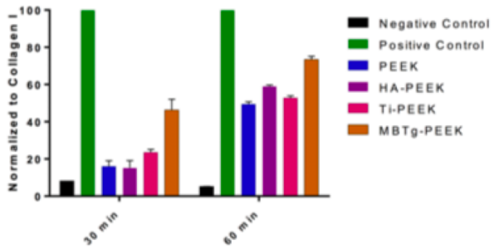
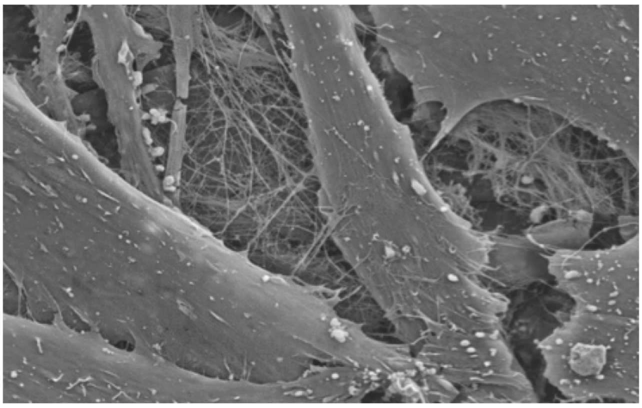


Figure: **MC3T3-E1 cells adhesion on PEEK materials.** MC3T3-E1 cells were starved for 8 hours. Cells (1x10^5 cells/µL) were seeded in wells coated with BSA (10µg/mL) and Collagen I (25µg/mL) or containing PEEK material and were allowed to adhere for 30 min and 60 min respectively. After fixation and washing, adherent cells were stained with crystal violet and the absorbance was measured at 590nm. Each sample was analyzed in triplicate and results displays here are from three independent experiments. Mean absorbance were normalized to Collagen I adhesion after 2hrs.The histogram represens mean percentage of adhesion±SD.

Conclusion. Intensive testing in vitro and in vivo demonstrated safety and performance of the unique biochemical implant surface PEEK-MBT. Test set up was chosen to compare MBT material surfaces against Titanium and HA-enhanced PEEK materials. PEEK-MBT showed osseointegrative characteristics that are significant superior to PEEK, HA-enhanced PEEK and Titanium, known as the golden standard for orthopedic and dental implant materials.



Pic. 3 - stimOS PEEKMBT:Secretion of a large amount of extra-cellular collagen matrix and start of mineralization after already 12 hours – cells grow in several compact layers and the calcification process started.

The animal model (sheep) and in vitro cell tests demonstrated the overall biocompatibility of the new developed surface modification MBT.

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