Multiwalled Carbon Nanotubes Grown from Anodized Titanium for Sensing New Bone Growth

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Statement of Purpose: Metallic titanium widely used in orthopedic applications is biocompatible due to its oxide layer, which forms to reduce its surface free energy. However, titanium implant failure has occurred due to loosening or infection. Typically, the biological interactiveness of biomaterials relates to their critical surface tension [1]. Surface roughness, topography, composition, and energy influences osseointegration and thus induces osteoblast differentiation *in vitro*. These surface properties mediate different initial protein interactions (absorption and bioactivity) to influence osteoblast adhesion. Therefore, multiwalled carbon nanotubes grown out of anodized titanium (MWCNT-Ti) [2] were evaluated by using contact angle measurements to find the critical surface tension/surface energy of this novel material in this study. Cyclic voltammetry of redox reactions were also conducted to compare the electrochemical responses of Ti, anodized Ti, and MWCNT-Ti electrodes necessary for the continued evaluation of MWCNT-Ti as *in situ* devices that can sense new bone growth next to implant surfaces.

Methods: Multiwalled carbon nanotubes were grown out of anodized Ti by chemical vapor deposition [2]. Cytocompatibility test procedures used with osteoblasts can be found elsewhere [2]. Electrochemical workstation and Digisim software (Bioanalytical) performed the cyclic voltammetry experiments in this study. The Ti, anodized Ti, and MWCNT-Ti substrates were used as working electrodes. A silver/silver chloride and platinum wire were used as reference and counter electrodes, respectively. All electrodes were immersed in an electrolyte solution of the extracellular matrix components secreted from osteoblasts after they were cultured on conventional Ti for 7, 14, and 21 days. Cyclic voltammetry experiments were performed by applying a linear sweep potential. Contact angle measurements using the sessile drop method were recorded and analyzed using an easy drop model system (Kruess). The contact angle was immediately measured within 10 seconds after dropping 10 μl of each liquid, consisting of deionized water, glycerol, and polyethylene glycol.

Results: Multiwalled carbon nanotubes (MWCNTs) were successfully grown out of anodized Ti nanopores as shown in Figure 1. We performed these experiments with a solution of osteoblast secreted extracelluar matrix components after 7, 14, and 21 days of culture. Results showed that redox reactions were observed only when using MWCNT-Ti, not when using anodized Ti and conventional Ti. The peaks have higher faradic currents with respect to the extracellular matrix solution collected after 7, 14, and 21 days of osteoblast culture. Surface energy was calculated from advancing contact angles by using three liquids with Ti, anodized Ti, and MWCNT-Ti. The surface energy from the four methods (Zisman, Equation of States, Owen-Wendt, and Acid-Base approaches) was completed with calculation software DSA (Drop Shape Analysis; version 1.90.0.14; Kruess; Germany). MWCNT-Ti had the highest critical surface tension, following the Zisman approach, and the greatest osteoblast differentiation. From the Owens-Wendt model, which related surface energy via an interaction parameter (such as polarizabilities and ionization potential), anodized Ti was shown to have the highest polar component (1/3 of the total surface energy approximately), while Ti and MWCNT-Ti had major contributions from the dispersive component. From the Acid-Base approach, results showed that the dispersive component of Ti and MWCNT-Ti mainly contributed to the Lifshitz-van der Waals component.

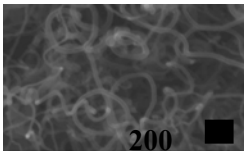

Figure 1. SEM micrograph of MWCNT-Ti.

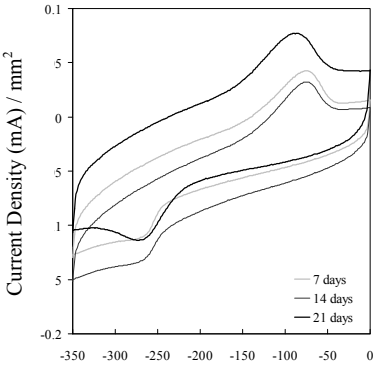

Figure 2. Cyclic voltammograms of MWCNT-Ti electrodes in an electrolyte solution of the extracellular matrix components secreted from osteoblasts after they were cultured on conventional Ti for 7, 14, and 21 days.

Conclusions: The critical surface tension of the MWCNT-Ti is considered a key factor in modulating osteoblast functions. This may explain the previously observed enhanced cytocompatibility properties of MWCNT-Ti with osteoblasts compared to currently implanted Ti. In summary, not only do MWCNT-Ti have a higher critical surface tension and promote osteoblast differentiation, but also MWCNT-Ti can be useful to detect the osteoblast redox activities *in situ* as an electrochemical electrode surrounding an orthopedic implant to determine if bone growth is occurring.

References:

[1] Ratner BD, Hoffma AS, Schoen FJ, and Lemons JE, 2004, *Biomaterials Science,* Elsevier, California, USA.

[2] Sirivisoot S, Yao C, Xiao X, Sheldon BW, and Webster TJ, *Nanotechnology*, vol. 18, 365102, 2007.