Review Article
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The application of nanotechnology in biomechanical systems: recent developments

Abstract

Nano materials are used widely in today's life. Engineering fields are mostly made use of such substances. In biomechanical engineering the use of nanomaterial is no that famous. Today's studies are focusing in utilizing the Nano technology in engineering materials. However, Viscoelastic behavior has been largely ignored. In this work a mini review of current studies where nano materials is utilized in biomechanical systems is presented. For example, a characterizing the micro-mechanical viscoelastic properties of cross-linked hydrogels at typical cell length scales is presented. An advanced ceramic conversion surface engineering technology has been applied for the first time to self-drilling Ti6Al4V external fixation pins to improve their performance in terms of biomechanical, biotribological and antibacterial properties. Characterization of the ceramic conversion treated Ti pins was carried out using nano- and micro-indentation and scratching.

Results of this review show that an empirical equation describing the stress-time relation can be derived from experimental data. The use of nanomaterial helps in improving the mechanical properties of the tissues under study. The mechanical properties of Ti pins are significantly increased hardness (more than three times) and the effectively enhanced wear resistance. The maximum insertion force and temperature were reduced from 192N and 31.2°C when using the untreated pins to 182N and 26.1°C when the ceramic conversion treated pins were tested.

Keywords: nano-materials, biomechanical, viscoelastic, pins

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Introduction

Nanotechnology which involves handling with materials at very small dimensions (10^{-9}m) has wide applications in engineering branches. It can improve the physical and chemical properties of the system. Thus it has many applications such as solar desalination[1] and many others. Current researches are trying to involve these substances in biomechanical engineering systems. For example one of important properties in biomechanical systems is viscoelasticity of cells that are surrounded by the extracellular matrix (ECM), which is complex network of glycosaminoglycan, proteins, and fibers[2] that provide biochemical and biomechanical cues that are critical for the regulation of cell adhesion, proliferation, differentiation, morphology, and gene expression so the ECM is vital for soft tissue biomechanics. Cell response to stiffness as well has contributed to the behavior of cell mechano-transduction, designating substrate elasticity as a major determinant in the regulation of Pathophysiological cell behavior and function.[3,4]

Generally speaking mechanical properties should be derived in the physiological region of small deformations (e.g., the 0.01÷0.1 strain range), and measurements should be performed at physiologically relevant strain rates/frequencies (e.g., a $0.001 \div 0.1 s^{-1}$ strain rate).[5–7] Developing biomaterials for cell culture and mechano-biology studies. To date, only a few cells (hMSCs), but decreased the size and maturity of their focal adhesions. Another example is the external fracture fixation that entails the use of percutaneously placed transosseous pins and/or wires secured to external scaffolding to provide support to a limb. These include highly comminuted fractures, open fractures, fractures associated with gross soft tissue damage. Currently, external fixation has evolved from being used as a last resort fixation method to a main technique to treat a myriad of bone and soft tissue pathologies. To ensure a solid fixation, ease of insertion and reduce risk of complications a well-designed pin is required. Stainless steel and titanium self-drilling/self-tapping Schanz pins are one of best choices.[8]

Austenitic stainless steel is the material selected for external fixation pins. This is attributed to the attractive combination of excellent corrosion resistance, good mechanical properties and adequate biocompatibility coupled with their outstanding formability and cost-effectiveness.[9] The coming section will present the up-to-date development in the above mentioned examples.

Discussion of recent developments

Bio mechanical properties

In their work[10] researchers used the nano-$\dot{\varepsilon}$ M to characterize the micro-mechanical viscoelastic properties of gelatin hydrogels. Gelatin is widely used as cell culture substrate because of its inherent biocompatibility and bioactivity.[11] Many studies have focused on characterizing the quasi-static elastic modulus (E) of GTA-cross linked gelatin hydrogels, showing an increase in E with increasing GTA concentration.[12,13] The micro-mechanical Visco elastic properties of GTA-cross linked gelatin hydrogels were characterized via nano indentation tests, relating results to the cross linker concentration.

The experimental results obtained[10] were fitted to a Maxwell Standard Linear Solid model, showing that increasing GTA concentration results in increased instantaneous and equilibrium elastic moduli and in a higher characteristic relaxation time. Therefore, not only do gelatin hydrogels become stiffer with increasing cross linker concentration but there is also a concomitant change in their viscoelastic behavior towards a more elastic one. The experimental data allows the derivation of stress – time relation expressed in Eq. (1):

$$\sigma_{ind}(t) = \dot{\varepsilon}_{ind} \cdot \left(E_0 t + \eta_1 \left(1 - e^{-\frac{E_1}{\eta_1} t} \right) \right) \quad (1)$$

Eq. (1) consists of a pure spring (E_0) assembled in parallel to a Maxwell arm (i.e., a spring E_1 in

Series with a dashpot η_1, defining a characteristic relaxation time $\tau_1 = \frac{\eta_1}{E_1}$.

Pin fixation

Nanotechnology showed a great improvement in the field of pin fixation.[14] In coating processes it is well known that titanium and its alloys are described as poor mechanical properties in terms of low hardness and low load bearing capacity. In addition poor tribological properties in terms of low hardness, high friction and strong adhesive wear[15,16] are recorded. Therefore, without strong mechanical support from the substrate, the very thin (nanometric) TiO_2 films formed in air at room temperature.[17] This led to the loss of the anti-bacterial property. A problem of high temperature at bone-pin surface during insertion occurs, which would cause damage to the bone and retard its healing after operation.[18]

Thus researchers[14] report a novel approach to generate a multi-functional surface for titanium Schanz pins by converting their Ti surfaces into a TiO_2 ceramic layer through thermal oxidation of Ti in an oxygen-containing atmosphere. Oxygen diffuses into the subsurface to form a hardened case which can provide a strong mechanical support to the surface TiO_2 ceramic layer, thus effectively conferring a high load bearing capacity of the CCT treated Ti surfaces. Characterization of the ceramic conversion treated Ti pins was carried out using scanning electron microscope, X-ray diffraction, Glow-discharge optical emission spectroscopy, nano- and micro-indentation and scratching; the biomechanical and bio-tribological properties of the surface engineered Ti pins were evaluated by insertion into high density bone simulation material; and the antibacterial behavior was assessed with Staphylococcus aureus NCTC 6571. The experimental results have showed that the surfaces of external fixation pins were successfully converted into a TiO_2 rutile supported by an oxygen hardened case with very good bonding due to the in-situ conversion nature.

Conclusion

Nano materials have strong contribution in the field of biomechanical systems. Starting from improving the physical properties such as the hardness and viscoelasticity to improve the pin fixation processes. Where the force on the pin is minimized and the temperature is reduces due to friction. This allows a long lasting of the pin. Nano- and micro-indentation and scratching are used for systematic characterization of the ceramic conversion treated Ti pins.

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Conflict of interest

Author declares that there is no conflict of interest.

References

1. Hani EB, Borgford C, Khanafer K. Applications of porous materials and nanoparticles in improving solar desalination systems, *Journal of porous media*. 2016;19(11):993–999.
2. Frantz C, Stewart KM, Weaver VM. The extracellular matrix at a glance. *J Cell Sci*. 2010;123(24):4195–4200.
3. Watt FM, Huck WTS. Role of the extracellular matrix in regulating stem cell fate. *Nat Rev Mol Cell Biol*. 2013;14(8):467–473.
4. Mason BN, Califano JP, Reinhart-King CA. Matrix stiffness: A regulator of cellular behavior and tissue formation. *Eng Biomater Regen Med*. 2012;1:19–37.
5. Mattei G, Ahluwalia A. Sample, testing and analysis variables affecting liver mechanical properties: A review. *Acta Biomater*. 2016;45:60–71.
6. Mattei G, Tirella A, Gallone G, et al. Viscoleastic characterisation of pig liver in unconfined compression. *J Biomech.* 2013;47(11):2641–2646.
7. Tirella A, Mattei G, Ahluwalia A. Strain rate viscoelastic analysis of soft and highly hydrated biomaterials. *J Biomed Mater Res Part A*. 2014;102(10):3352–3360.
8. Wikenheiser MA, Market MD, Lewallen. Thermal response and torque resistance of five cortical half pins under simulated insertion technique. *J Orthop Res*. 1995;13(4):615–619.
9. Davis JR. Handbook of materials for medical devices. *Materials Park: ASM International*. 2003. p. 27–28.
10. Mattei G, Cacopardo L, Ahluwalia A. Micro-Mechanical Viscoelastic Properties of Crosslinked Hydrogels Using the Nano-Epsilon Dot Method. *Materials*. 2017;10(8):889.
11. Dawson E, Mapili G, Erickson K, et al. Biomaterials for stem cell differentiation. *Adv Drug Deliv Rev*. 2008;60(2):215–228.
12. Mattei G, Ferretti C, Tirella A, et al. Decoupling the role of stiffness from other hydroxyapatite signalling cues in periosteal derived stem cell differentiation. *Sci Rep*. 2015;5:10778.
13. Bigi A, Cojazzi G, Panzavolta S, et al. Mechanical and thermal properties of gelatin films at different degrees of glutaraldehyde crosslinking. *Biomaterials*. 2001;22(8):763–768.
14. Dong H, Mukinay T, Li M, et al. Improving tribological and anti-bacterial properties of titanium external fixation pins through surface ceramic conversion. *J Mater Sci Mater Med.* 2017;28(1):5.
15. Hutchings IM. *Tribology: Friction and wear of engineering materials*. UK; 1992. p. 273.
16. Dong H, Bell T. Enhanced wears resistance of titanium surfaces by a new thermal oxidation treatment. *Wear*. 2000;238(2):131–137.
17. Rabinowicz E, Kingsbury EP. Lubricant of titanium. *Met Prog*. 1995;67(5):112–114.
18. Eriksson RA, Albrektsson T. The effect of heat on bone regeneration: An experimental study in the rabbit using the bone growth chamber. *J Oral Maxil Surg*. 1984;42(11):705–711.

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