The Effect of Short Voltage Pulses on the Passivation of 316L Stainless Steel.

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Previous studies have shown that short voltage pulses can change the nature of surface oxides present on stainless steels, although these have concentrated on pulse widths of several milliseconds or greater [1,2]. Stainless steels are one of the three main alloy classes used in metallic orthopedic implants, along with titanium and cobalt-chromium alloys [3]. In all three alloy systems, a passive oxide film provides effective corrosion resistance against the aggressive environment of the human body. The passive film is not inert, and so ions in the film may still be released into the surrounding environment. Studies investigating the release of metal ions *in vitro* suggest only low concentrations of ions are released into the body under normal conditions [3]. We have investigated the role sub-millisecond voltage pulses could have on the passivation of, and ion release from, orthopedic implant materials. This study presents, to our knowledge, the first investigation into this phenomenon.

We have investigated the effect of short voltage pulses on 316L stainless steel. A novel cell was designed to hold a 316L plate halfway between two platinum electrodes in such a way that no solution or current could flow around the plate. The platinum electrodes were electrolytically connected to the main cell in a way that prevented contamination of the stainless steel sample or electrolyte in the main cell. By separating the platinum electrodes in this way, the generation of oxygen and hydrogen on the platinum surface was also unable to affect the pH of the solution in the main cell. This simulation is a simplification of what may occur when implants *in vivo* experience voltage pulses from external fields, where it could be expected that a proportion of the current could flow around the implant through the neighboring human tissue. Ringer's solution was used as the electrolyte to simulate the ion concentrations found in body fluids. Experiments were performed at room temperature or 37°C and the results compared. A 30 minute period elapsed before pulsing was started in order to let the system approach a steady state. Unidirectional square pulses of up to 10V and of between 100 μs and 10 ms pulse width were applied across two platinum electrodes at frequencies of up to 100Hz. This exposed the stainless steel sample to a pulsed electrode potential. The minimum duration of pulsing was 30 minutes. The potential of the sample was monitored throughout the experiment and for at least 30 minutes after pulsing had ceased. The potential response of the stainless steel was recorded relative to a saturated calomel electrode via an oscilloscope, which captured a snapshot of the potential trace once every two minutes. This enabled both short-term and long-term potential responses to be recorded. The method is, we believe, unique for this type of system.

The results show that applying voltage pulses induces changes in the potential of the 316L stainless steel. The steel is polarized indirectly by the application of the voltage pulse between the two platinum electrodes. The extent of the potential response to an individual pulse is dependent on the pulse width and frequency of pulsing, as well as the magnitude of the applied pulse and the initial potential of the alloy. After a pulse has ended, the potential of the sample does not return to the pre-pulse potential for a period of time of at least 10 times the pulse width, and when certain combinations of pulse parameters are applied, a period of pulsing can cause a change in the potential which remains for at least 1 hour after the end of repetitive pulsing.

In order to determine whether this long-term potential change results from changes to the passive film, two further sets of data were collected. The change in impedance properties of the 316L passive film as a result of exposure to 1 hour of pulsing was investigated using electrochemical impedance analysis (EIS). To determine the effect a single voltage pulse has on the passive film, a potentiostatic pulse technique was used to determine the residual charge density transfer resulting from a single pulse. The potential pulse applied had the same magnitude as the potential response seen when the 316L stainless steel was exposed to voltage pulses between two platinum electrodes. Results are presented showing the extent to which Faradaic reactions may occur on the surface of the stainless steel due to a single applied voltage pulse.

References.

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