Evaluation of mechanical and corrosion biocompatibility of TiTa alloys

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As-received and heat-treated Ti40Ta and Ti50Ta alloys were evaluated to determine their corrosion as well as mechanical performances and compared to Ti6A14V, a common material utilized for orthopedic (surgical) implants. Anodic potentiodynamic tests performed in Plasmalyte™ showed that all samples, except for the Ti50Ta specimen aged at 400 °C for 3 h gave a curve similar to that of Ti6A14V. Optical and TEM microscopy was performed to determine as-received and heat-treated microstructures. As-received materials showed an α precipitate in an α + β and martensite matrix. Samples that were aged at 400 °C increased in the density and the length of the α precipitate. Vickers hardness measurements were performed to get an approximation of the tensile strengths. Aged Ti40Ta and Ti50Ta specimens produced the highest tensile values when compared to the Ti6A14V material, representing a 31% and 56% increase for the 3 h samples and an 18% and 58% increase for the 10 h samples. Of all the materials studied the Ti50Ta specimen aged for 10 h exhibited the best biocompatibility showing excellent corrosion resistance combined with the highest tensile strength (1089 MPa and 58% harder/stronger than Ti6A14V).

1. Introduction
Metallic implant materials such as commercially pure (CP) Ti and Ti6A14V have experienced a trend of growing interest especially as orthopedic and surgical reconstructive implants. Their high corrosion resistance and strength-to-weight ratio properties make them ideal materials for bioimplantation. In addition, these materials exhibit relatively high fatigue strengths and are nonthrombogenic.

Of recent concern, however, is the presence of Ti ions that have appeared in several clinical studies involving Ti6A14V and CP Ti [1–8]. In large amounts Ti may hinder the recovery process by increasing the amount of local inflammation. With current trends leaning toward longer implantation times and larger surface areas the issue of Ti toxicity becomes a real concern.

It is the aim of this paper to determine the biocompatibility of two Ti-Ta alloys (Ti40Ta and Ti50Ta) as potential replacements for the current Ti alloys. Tantalum is currently used in surgeries involving vascular axes and secretory canals [9, 10] and is also a material that exhibits high corrosion resistance. Few researchers have performed biocompatibility studies on Ti-Ta alloys and have mainly centered their efforts on Ti5Ta [11]. In this study, anodic polarization curves were performed on the two alloys to determine passive behavior under several different heat-treatment conditions. Optical as well as transmission electron microscopy (TEM) have been performed to characterize the resulting heat-treated microstructures. Vickers microhardness tests were performed to monitor aged microstructural variations and to obtain an estimate of the tensile strengths of all the samples.

2. Experimental procedures
The Ti40Ta and Ti50Ta materials were received in billet form and had compositions like those listed in Table I. The major alloying elements are Ti and Ta with some trace impurities of Fe, Si, Al and C. Samples of approximately 0.6 cm diameter disk areas were sectioned. Ti6A14V samples were also sectioned from rod material and was used in these experiments as a biomaterial control.

Four different heat-treatments were carried out on all three materials. Set one was heat-treated to 1000 °C for 1 h and then water quenched. Set two was carried out at the same temperature and time but furnace cooled. Set three was aged at 400 °C for 3 h and then water quenched. Set four was aged at 400 °C for 10 h and then water quenched. All heat-treatments were carried out in an Ar atmosphere.

Samples were mechanically polished using SiC paper and then fine polished with 1.0 micron and 0.3 micron alumina slurries, and then colloidal silica. Samples were then washed in a mild soap solution and rinsed thoroughly with distilled water and ethanol.

Potentiodynamic tests were then performed on all samples using Plasmalyte™, a simulated biological solution at 0.17 m V/s vs SCE. Scans were run only on the anodic side of the potentiodynamic curve to compare the passive behaviors of the materials. Samples were then...
chemically polished in preparation for optical microscopy. The chemical polish solution consisted of 25 ml lactic acid, 15 ml HNO\textsubscript{3} and 5 ml HF. To further enhance grain structure an etching solution of 20 ml HNO\textsubscript{3}, 20 ml HF and 60 ml H\textsubscript{2}SO\textsubscript{4} was utilized. In some instances, a stronger etching solution of 80\% HF in H\textsubscript{2}O was utilized.

Thin sections were then obtained for TEM. Three mm discs were punched from approximately 200 \textmu m thick foils of all the materials. The jet polishing solution consisted of 150 ml HCl, 50 ml HF and 1400 ml methanol at 10\textdegree C. A Hitachi H-8000 Scanning Transmission Electron Microscope operating at 200 kV was used in order to observe internal microstructure.

An estimate of the tensile strengths of the Ti-Ta alloys was obtained from Vickers microhardness data. These values were also converted to Brinell hardness and then multiplied by a factor of 350 (used for non-ferrous alloys) to obtain approximate tensile strengths in psi.

3. Results
The anodic polarization curves for the as-received as well as 1000 \textdegree C heat-treated samples are recorded in Figs 1 and 2. All samples show that a stable passive layer has formed on the material surface at low current densities. The as-received Ti40Ta (Fig. 1a) and Ti50Ta (Fig. 1b) materials exhibit the same kind of polarization slope as that of Ti6A14V (Fig. 1c) which was included as a biomaterial standard reference. The samples that have been heat-treated at 1000 \textdegree C and quenched (Fig. 2a and b) and furnace cooled (Fig. 2c and d) show a much steeper passive slope yet exhibit a passive current density of approximately $1 \times 10^{-1} \mu A/cm^2$ similar to the as-received Ti6A14V sample.

The aged samples (400 \textdegree C) display a variation in polarization curves. Although the Ti40Ta sample treated for 3 h (Fig. 3a) has a stable passive layer it occurs at a higher current density than the as-received and 1000 \textdegree C

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ta</th>
<th>Fe</th>
<th>Si</th>
<th>Al</th>
<th>C</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti40Ta</td>
<td>37.8</td>
<td>0.18</td>
<td>0.1</td>
<td>0.05</td>
<td>0.01</td>
<td>Balance</td>
</tr>
<tr>
<td>Ti50Ta</td>
<td>45.6</td>
<td>0.4</td>
<td>0.18</td>
<td>0.05</td>
<td>0.01</td>
<td>Balance</td>
</tr>
</tbody>
</table>

*Figure 1* Potentiodynamic scans for the (a) Ti40Ta, (b) Ti50Ta and (c) Ti6A14V materials in the as-received condition. The TiTa alloys agree very well with the Ti6A14V material.