Effect of Plasma Treatment of PEEK on Bacterial Adhesion


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Introduction:
There is currently significant interest in using Polyetheretherketone (PEEK) as a replacement for metals in devices such as spine cages and craniomaxillofacial implants. The material properties of PEEK, such as radiolucency, high strength and good wear resistance have led to this polymer being used in a wide range of biomedical applications.

However, as a result of the low surface energy of PEEK, eukaryotic cell interactions to PEEK can be limited. Oxygen plasma treatment can be used to increase surface energy and has been shown to improve osteoblast adhesion to PEEK. Oxygen plasma surface treatment has also been shown to reduce adhesion of bacteria to polyvinyl chloride.

To date, bacterial adhesion to oxygen plasma treated PEEK has not been investigated. This in vitro study therefore compares the adhesion of clinically relevant bacteria to untreated PEEK versus oxygen plasma treated PEEK using Thermanox and standard micro-rough medical grade titanium as control surfaces.

Materials and Methods:
Modification of 13mm diameter medical grade injection moulded PEEK Optima discs (Invibio Ltd.,UK) was conducted by oxygen plasma treatment for 10 or 30 minutes using an EMITECH radio frequency plasma treater. Thermanox (Nunc, DK), Titanium ISO 5832/2 (Synthes Inc., CH) and untreated machined and injection moulded PEEK Optima discs were used as the control surfaces. Surface analysis of the test materials was conducted to characterise: the surface chemical compositions using X-ray photoelectron spectroscopy (XPS), wettability by water contact angle and topography by atomic force microscopy (AFM) and scanning electron microscopy (SEM). A clinical isolate of S. epidermidis, strain 138, was grown to log phase. The bacterial suspension was diluted to 1x10^7 cfu/ml. A litre of the bacterial suspension was then sonicated for 5 minutes, and finally vortex mixed for 20 s to remove the debris. The samples were then placed in individual bottles of sterile PBS, incubated for 7 days, sonicated for 5 minutes, and finally vortex mixed for 20 s to remove the debris. The samples were then placed in individual bottles of sterile PBS, sonicated for 5 minutes, and finally vortex mixed for 20 s to remove the adhered bacteria. Serial dilutions were immediately performed using a method adapted from Miles and Misra and total viable counts were taken after 18 h incubation at 37°C. Statistical analysis was performed using SPSS v.16.0. A unpaired T-test was used to compare the surface roughness of all the test materials. A one-way ANOVA was used to test for differences between the bacterial adhesion. Significance was identified at P<0.05.

Results:
The results of the surface analysis are described in table 1. AFM showed that machined PEEK and titanium have a similar roughness, both of which were significantly rougher than injection moulded PEEK and Thermanox. In addition, the surface roughness of Thermanox was significantly lower than that of injection moulded PEEK.

<table>
<thead>
<tr>
<th>Material</th>
<th>Ra [μm]</th>
<th>WCA [°]</th>
<th>Atom % oxygen</th>
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<tbody>
<tr>
<td>Thx</td>
<td>1.73 ±0.04</td>
<td>63.53 ±7.04</td>
<td>14.46 ±1.11</td>
</tr>
<tr>
<td>PA</td>
<td>423.60 ±141.27</td>
<td>68.26 ±9.67</td>
<td>11.66 ±0.32</td>
</tr>
<tr>
<td>Ti</td>
<td>364.50 ±101.25</td>
<td>72.73 ±3.12</td>
<td>47.48 ±6.57</td>
</tr>
<tr>
<td>PO 0</td>
<td>72.86 ±11.56</td>
<td>83.43 ±6.03</td>
<td>11.51 ±0.26</td>
</tr>
<tr>
<td>PO 10</td>
<td>75.17 ±9.96</td>
<td>59.99 ±2.21</td>
<td>14.15 ±0.35</td>
</tr>
<tr>
<td>PO 30</td>
<td>93.03 ±26.64</td>
<td>59.02 ±6.49</td>
<td>16.14 ±0.66</td>
</tr>
</tbody>
</table>

Thermanox (Thx), machined PEEK (PA), titanium (Ti), moulded PEEK (PO 0), injection moulded PEEK treated for 10 minutes (PO 10) and injection moulded PEEK treated for 30 minutes (PO 30).

Analysis of the surface chemistry and wettability showed the injection moulded PEEK to be relatively hydrophobic. The wettability of machined PEEK indicated that these surfaces were more hydrophilic than the injection moulded PEEK. However, XPS analysis reported no difference in surface chemical composition between the two surfaces, demonstrating the influence of roughness on wettability measurements. Titanium had a higher level of surface oxygen, approximately 48 atom %, making it relatively hydrophilic, which was reflected in the water contact angle measurements. Surface treatment of the injection moulded PEEK resulted in an increase in surface oxygen, and a decrease in the water contact angles, confirming that these surfaces had become more hydrophilic than the untreated PEEK surfaces. The longer treatment time of 30 minutes also resulted in a slight increase in surface roughness, where some pitting could also be observed.

Figure 1. Mean adhesion of S. epidermidis 138 to titanium (Ti), Thermanox (Thx), machined PEEK (PA), injection moulded PEEK and the plasma treated surfaces (PO 0, PO 10 & PO 30) ± St. Dev. The brackets denote that there was no significant difference between treated and untreated injection moulded PEEK.

The results of the S. epidermidis 138 adhesion to the test surfaces are illustrated in Figure 1. Adhesion of S. epidermidis to the control materials corresponded primarily to topography, with the average bacterial adhesion increasing with increasing surface roughness. The increase in bacterial adhesion from 3.08x10^5 cfu/cm² on the smoothest surface, Thermanox, to 6.51x10^5 cfu/cm² on the roughest surface, machined PEEK, illustrates the influence of roughness on bacterial adhesion. There was no significant difference between the bacterial adhesion on the oxygen plasma treated injection moulded PEEK compared to the untreated injection moulded PEEK.

Discussion/Conclusions:
The results of this preliminary in vitro study report that adhesion of S. epidermidis 138 to injection moulded PEEK is not significantly altered by increasing surface energy. Instead, S. epidermidis 138 adhesion appears to be mainly influenced by topography. The analysis of a greater number of strains of S. epidermidis and other species, such as S. aureus, may help explain the effect of manufacturing method and oxygen plasma treatment of PEEK on bacterial adhesion. These initial findings suggest that surface treatment of PEEK to increase osseointegration does not influence the vulnerability of the material to bacterial adhesion.

References:

Acknowledgments:
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