IMPROVEMENT OF FIXATION SCREWS BY AMORPHOUS DIAMOND COATINGS

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INTRODUCTION
Different types of bone screws are widely used in orthopaedics and dentistry for fracture fixation. Screws must maintain geometric alignment, and transmit compressive and tensile forces across fracture site. The fixation device should also allow favourable mechanical and biological conditions for healing [1]. The forces required in bone screw installation are affected by several factors such as the screw diameter and length, the shape of the screw thread and the density of bone [2,3]. Several methods have been used for surface treatment of bone screws. Common methods include electrolytic polishing, etching, and different kinds of coatings. Important properties that should be enhanced by surface modifications include wear resistance and biocompatibility. Amorphous diamond (AD) is reported to be a very hard, inert coating with low friction against most of materials [4]. Therefore, AD coatings should improve biocompatibility, reduce the number of screw failures, and make late removal easier. In this study, potential of AD coating to reduce screw insertion torque was studied with custom-made equipment corresponding to ASTM standard for testing metallic bone screws.

METHODS
In preliminary tests, self-tapping cortical bone screws were used. The stainless steel alloy screws had a diameter of 2.7 or 3.5 mm and a length of 50 mm. In the first tests, the screws were installed into a flat disc of Teflon and a flat piece of dry pine wood to test reproducibility of the equipment. Tests were accomplished according to ASTM standard F543-00. The screws were installed using 2.5 - 10.0 rpm as the rate of rotation. Maximum torque during the initial four revolutions was considered as the insertion torque for the experiment. The axial load on the screws was approximately 2.0 kg.

In the second series, a group of bone screws were installed into bovine cortical bone, which is harder and denser than human bone. Prior to testing, half of the screws were coated with amorphous diamond using method described in ref. [5]. For each screw, installation was accomplished up to the end of the screw or until the screw fractured (see Fig. 1 a).

RESULTS
Tests with self-tapping cortical bone screws and Teflon and wood samples showed that good reproducibility is achieved with the equipment (see Table 1). In the second test series, both the screws and the AD coating proved good durability. For the 2.7 and 3.5 mm thick cortical bone screws, the failure torques were 30 - 50 % higher than the minimum values required by standard, 1.0 Nm and 2.3 Nm, respectively. Testing with amorphous diamond coated bone screws confirmed good durability, and no delamination of the coating was observed. For the AD-coated screws, the torque values were on the average 10 - 15 % lower than for uncoated otherwise identical screws (Fig. 1 b).

DISCUSSION
The continuous recording, constant rate of rotation and avoiding side loads on the screws in our present set-up allows us to observe oscillations in torque, e.g. due to torsional stiffness of the screw and stick-slide motion with high accuracy.

In our study, the insertion torque increased slightly with the rate of rotation, which is evidently due to the plastic behaviour of wood and Teflon. The insertion torque increased roughly as the square of the screw diameter, which agrees with the simple rule based on the size of the screw. Already the preliminary testing with amorphous diamond coated bone screws showed good durability of the coating and resulted in lower torque values compared with uncoated screws. Our future aim is to determine whether amorphous diamond coatings lower the insertion torque in human bone samples. Retrieved screws will also be tested to study the long-term behaviour and stability of screw materials with different surface treatments.

Table 1. Insertion torques for wood and Teflon. Left; screw diameter 2.7 mm and right; screw diameter 3.5 mm. Values are presented as the mean ± STD (N = 6). Roe = “rate of rotation”.

<table>
<thead>
<tr>
<th>Roe (1/min)</th>
<th>τwood (Nm)</th>
<th>τTeflon (Nm)</th>
<th>Roe (1/min)</th>
<th>τwood (Nm)</th>
<th>τTeflon (Nm)</th>
</tr>
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<tbody>
<tr>
<td>2.5</td>
<td>0.14 ± 0.02</td>
<td>0.08 ± 0.02</td>
<td>2.5</td>
<td>0.14 ± 0.02</td>
<td>0.08 ± 0.02</td>
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<tr>
<td>5</td>
<td>0.17 ± 0.03</td>
<td>0.11 ± 0.02</td>
<td>5</td>
<td>0.17 ± 0.03</td>
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<tr>
<td>7.5</td>
<td>0.17 ± 0.02</td>
<td>0.15 ± 0.03</td>
<td>7.5</td>
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<tr>
<td>10</td>
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<td>0.17 ± 0.05</td>
<td>10</td>
<td>0.18 ± 0.03</td>
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Fig. 1. a) A fractured bone screw is shown on the left and an unused bone screw on the right. The inserts show optical micrographs of the screws. Note the apparent damage to the threads of the fractured screw. b) The solid line indicates the insertion torque for a screw that was fractured during insertion, and the dotted line for a coated screw that did not fracture.

REFERENCES