The insertion of dental implants containing titanium can be associated with various complications (eg, hypersensitivity to titanium). The aim of this article is to evaluate whether there are existing studies reporting on PEEK (polyetheretherketone) as an alternative material for dental implants. A systematic literature search of PubMed until December 2010 yielded 3 articles reporting on dental implants made from PEEK. One article analyzed stress distribution in carbon fiber-reinforced PEEK (CFR-PEEK) dental implants by the 3-dimensional finite element method, demonstrating higher stress peaks due to a reduced stiffness compared to titanium. Two articles reported on investigations in mongrel dogs. The first article compared CFR-PEEK to titanium-coated CFR-PEEK implants, which were inserted into the femurs and evaluated after 4 and 8 weeks. The titanium-coated implants showed significantly higher bone-implant contact (BIC) rates. In a second study, implants of pure PEEK were inserted into the mandibles beside implants made from titanium and zirconia and evaluated after 4 months, where PEEK presented the lowest BIC. The existing articles reporting on PEEK dental implants indicate that PEEK could represent a viable alternative material for dental implants. However, further experimental studies on the chemical modulation of PEEK seem to be necessary, mainly to increase the BIC ratio and to minimize the stress distribution to the peri-implant bone.

Key Words: PEEK, dental implants, finite element method, animal experiments, osseointegration
Furthermore, the stress distribution of a zirconia implant to the surrounding bone could be associated with even higher stress peaks compared to titanium, due to the higher elastic modulus of zirconia of 210 GPa.25 Another biocompatible material with an elastic modulus of 3.6 GPa, which is closer to that of bone, is polyetheretherketone (PEEK).26 Its modulus can be modified by reinforcing it with carbon fibers, for example, to achieve a modulus of 18 GPa, similar to that of cortical bone.27 Since PEEK showed resistance to degradation in vivo, it was offered commercially in April 1998 as a biomaterial for long-term implants (Invibio Ltd, Thornton-Cleveleys, UK).28 Since then, PEEK has demonstrated to be a high-performance thermoplastic polymer able to replace metallic implant components in the field of orthopedics29,30 and traumatology.31,32 Also, calvarial reconstructions with PEEK implants were described.33 These findings suggest that PEEK could substitute titanium as material for dental endosseous implants.

The current review pertains to literature published prior to December 1, 2010. The aim was to figure out whether there are existing studies about dental implants from PEEK, which probably underline the theory that PEEK could be considered as a viable alternative material for dental implants.

**MATERIALS AND METHODS**

**Literature search**

The articles for the current review were found using the PubMed search engine and searching for references cited within these articles. All articles published until December 2010 were reviewed. The following search terms were used together: “dental implant PEEK.”

**Inclusion criteria**

Only articles about dental implants from PEEK or modified PEEK published until December 2010 were included, regardless of the kind of investigation (in vivo or in vitro), implant design, surface modifications, year of publication, and language.

**RESULTS**

The search yielded 5 articles, of which 3 were included in the review.11,34,35 Two articles were excluded, because they did not report on dental implants of PEEK.36,37 Of the included articles, 2 reported on animal investigations34,35 and 1 on an in vitro finite element study.11 The aim of the 3-dimensional finite element study was to compare the stress distribution to the peri-implant bone in 4 distinct testing models consisting of either a titanium or a carbon fiber-reinforced PEEK (CFR-PEEK) implant, containing 30% carbon fibers to obtain an elastic modulus of 17.4 GPa similar to that of cortical bone,27 each in combination with a titanium and a CFR-PEEK abutment, completed with a cemented artificial crown (Table 1).

The CFR-PEEK implants presented a higher load concentration in the cervical area and at the cortical bone than the titanium implants, whereas the titanium implants presented equivalent stress peaks in the cervical portion and a more homogenous load distribution throughout the whole implant body (Table 1).

The authors admit that the higher stress concentrations of the PEEK implant were not expected. A more homogenous stress distribution was intended to diminish stress peaks at the implant-bone interface. So, they conclude that the CFR-PEEK implant did not present any advantages in comparison to the titanium implant.

This material was also used for cylindrical implants in an animal experiment, which compared the bone-implant contact (BIC) and shear strength of 20 titanium-coated implants to 20 uncoated implants.35 In this study 5 implants were inserted in each femur of 4 mongrel dogs, 5 uncoated on one side and 5 titanium-coated on the other side. After 4 and 8 weeks of healing, 2 dogs were sacrificed. Of each femur, 3 implants underwent pull-out testing to determine the mechanical integrity of the interface. The other 2 implants of each femur were reserved for intact histologic evaluation.

The coated implants showed significantly BIC values after a healing period of both 4 (P = .0014) and 8 weeks (P = .0261), whereas the BIC of both the uncoated and the coated implants generally decreased from 4 to 8 weeks. The shear strength for the uncoated implants was significantly higher after 4 (P = .0107) and lower after 8 weeks (P = .2496) (Table 2). The authors conclude that the addition of the titanium coating apparently increases the
| Table 1: Overview of an in vitro 3-dimensional finite element study* |
|------------------|------------------|------------------|
| **Author**       | Sarot et al11     |                  |
| **Year of publication** | 2009            |                  |
| **Implantation site** | Virtual 3-dimensional model of a lower jaw of region 35, based on a randomly chosen computerized tomography scan with a total of 212 transversal slices with 0.25 mm in length, consisting of medullar bone covered by a 1.0-mm thick layer of cortical bone, designed with the software Ansys DesignModeler v11 (ANSYS Inc, Canonsburg, Pa) |                  |
| **Simulation software** | Ansys Workbench V11 finite elements simulation software (ANSYS Inc) |                  |
| **Implant design** | Screwed cylindrical implant with a hexagon connection |                  |
| **Implant dimensions, mm** | Diameter: 4.1; length: 10 |                  |
| **Surface modification** | N.R.            |                  |
| **Roughness RA, μm** | N.R.            |                  |
| **Abutment design** | Outer hexagon |                  |
| **Abutment dimensions, mm** | 4.1, bottom platform with upper conic portion |                  |
| **Connection abutment/implant** | Titanium bolt with screws in the lower third |                  |
| **Prosthesis** | Chrome-cobalt structure with a thickness of at least 0.3 mm, covered by a feldspathic porcelain with coronary shape; an approximately 0.1-mm thick line of zinc phosphate cement was located between prosthesis and abutment |                  |
| **Implant material** | Titanium | CFR-PEEK with 30% carbon fiber |
| **Elastic modulus, GPa** | 110            | 18              |
| **Poisson ratio** | 0.35            | 0.39            |
| **Abutment material** | Titanium | Titanium |
| **Stress peaks in the different structures with vertical loads in relation to the long axis of the tooth with 100 N in magnitude, MPa** | von Mises implant 76.46; von Mises abutment 41.76; tensile cortical/medullar 32.70/2.48; compression cortical/medullar 81.14/3.19 | von Mises implant 85.54; von Mises abutment 41.32; tensile cortical/medullar 27.77/4.22; compression cortical/medullar 89.47/3.58 |
| **Tension peaks in the different structures with oblique load direction (30°) in relation to the long axis of the tooth with 100 N in magnitude, MPa** | von Mises implant 171.42; von Mises abutment 84.82; tensile cortical/medullar 22.02/2.65; compression cortical/medullar 146.26/3.95 | von Mises implant 188.95; von Mises abutment 69.96; tensile cortical/medullar 58.82/4.90; compression cortical/medullar 177.81/6.42 |

*N.R. indicates not reported.
biocompatibility of the implant surface. Using the BIC ratio as a parameter for the grade of osseointegration, it can be stated that both CFR-PEEK implants (coated and uncoated) presented a desirable osseointegration in comparison to the BIC values of the titanium implants (40.91 $\pm$ 10.11%) of the second animal experiment 34 (Table 2). The aim of that study was to evaluate osseointegration of 1-piece zirconia vs titanium implants depending on their insertion depths after a healing period of 4 months due to a split-mouth design (submerged vs nonsubmerged healing). Therefore, the test implants made from zirconia and coated zirconia (coated by a calcium-liberating titanium oxide [TiO$_2$] sol-gel layer) were compared to a control implant made from titanium. Additionally, an experimental implant of PEEK was inserted. All implants had the same design, only differing in their biomaterials. In this study, the PEEK implants reached BIC rates of 26 $\pm$ 8.9%.

In neither of the 2 animal investigations were signs of inflammation or foreign body reactions observed.

**DISCUSSION**

Referring to a 3-dimensional finite element analysis of a CFR-PEEK and a titanium implant (Table 1), the authors concluded that due to its higher stress concentrations, the CFR-PEEK implant could not be recommended.11

This deformation rate could probably be diminished by an inner stiffening of the implant, for example, by an abutment connection bolt which extends to the apical region of the implant, whereas the complete biomechanical behavior of a PEEK implant has to be tested experimentally to achieve accurate data.

Because CFR-PEEK is black due to the carbon fibers, its use could be unfavorable, especially in esthetic zones.

In an animal investigation from 1995, the BIC and shear strength of titanium-coated and uncoated CFR-PEEK implants were evaluated.35 The shear strength of the uncoated implants was significantly higher after 4 and insignificantly lower after 8 weeks of healing, although the BIC rate of the coated implants was always significantly higher (Table 2).

The surface roughness as an important factor was not assessed, so this phenomenon is difficult to interpret.

Considering potential hypersensitivities to titanium, in such cases a titanium coating might provoke hypersensitive inflammatory reactions.

The aim of the second animal experiment was to evaluate osseointegration of 1-piece implants made from zirconia, coated zirconia (coated by a calcium-liberating TiO$_2$ sol-gel layer), titanium, and PEEK.

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**Table 2**

Overview of 2 in vivo animal investigations*

<table>
<thead>
<tr>
<th>Author</th>
<th>Cook and Rust-Dawicki$^{35}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of publication</td>
<td>1995</td>
</tr>
<tr>
<td>Number of animals</td>
<td>4 (mongrel dogs)</td>
</tr>
<tr>
<td>Number of implants</td>
<td>40</td>
</tr>
<tr>
<td>Number of implants/animal</td>
<td>10</td>
</tr>
<tr>
<td>Implantation site</td>
<td>Femur</td>
</tr>
<tr>
<td>Healing period</td>
<td>4 weeks (n = 2); 8 weeks (n = 2)</td>
</tr>
<tr>
<td>Implant design</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>Healing method</td>
<td>Submerged/unloaded</td>
</tr>
<tr>
<td>Implant material</td>
<td>Chopped CFR-PEEK</td>
</tr>
<tr>
<td>Implant dimensions, mm</td>
<td>Diameter: 4; length: 10</td>
</tr>
<tr>
<td>Surface modification</td>
<td>Ti-coated uncoated</td>
</tr>
<tr>
<td>Roughness RA, $\mu$m</td>
<td>N.R.</td>
</tr>
<tr>
<td>Elastic modulus, GPa</td>
<td>N.R.</td>
</tr>
<tr>
<td>Shear strength, MPa</td>
<td>5.62 $\pm$ 1.97 (n = 10; 4 wk), 8.41 $\pm$ 2.67 (n = 10; 8 wk)</td>
</tr>
<tr>
<td>BIC, %</td>
<td>66.7 $\pm$ 21.76 (4 wk), 60.18 $\pm$ 24.48 (8 wk)</td>
</tr>
</tbody>
</table>

*M.R. indicates not reported.
depending on their insertion depths after a healing period of 4 months due to a split-mouth design (submerged vs nonsubmerged healing).\textsuperscript{34} Regrettably, the resulting BIC values of both the submerged and the nonsubmerged implant groups of this study were summarized to a mean value (Table 2). The different types of healing could have had an influence on the BIC values, due to different exposures of the implants to masticatory loads and oral flora.

For histomorphometric analysis, the bone level (BL) between the uppermost thread and the crestal bone level was subdivided into 2 sections. One section described the bone-related BL, ranging from the crestal bone level to the uppermost BIC. The other section was named implant-related BL, measured from the uppermost thread to the uppermost level of BIC. The level of the uppermost BIC was localized between the uppermost thread and the crestal bone level. All results, however, were expressed as negative values (Table 3). The authors argue that the bone levels in general presented higher values in the group of the submerged implants due to higher insertion depths, which were defined neither before nor while the implants were inserted. To get the mean insertion depths of the uppermost threads in relation to the crestal bone level, we took the values of the mean bone-

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Extended</th>
</tr>
</thead>
</table>

Koch et al\textsuperscript{34}  
2010  
6 (mongrel dogs)  
48  
8  
Mandible (split-mouth design)  
4 months  
Screwed 1-piece implant (all groups identical)  
Submerged/unloaded  
Titanium zirconia PEEK  
N.R. N.R. N.R.  
Caliberating TiO\textsubscript{2} sol-gel layer  
1.5–3 1.5–3 1.5–3  
110 200–220  
N.R. N.R. N.R.  
40.91 ± 10.11 59.11 ± 7.45 55.83 ± 13.92  
6 8 4 8 4 8  
Nonsubmerged/unloaded, with antagonistic teeth remained  
Titanium zirconia PEEK  
N.R. N.R. N.R.  
Caliberating TiO\textsubscript{2} sol-gel layer  
1.5–3 1.5–3 1.5–3  
110 200–220  
N.R. N.R. N.R.  
40.91 ± 10.11 59.11 ± 7.45 55.83 ± 13.92  
6 8 4 8 4 8  

*Distance from the crestal BL to the uppermost implant thread, calculated by the authors of the current review by adding bone-related BL and implant-related BL.
related BL and the mean implant-related BL from the original article and added them together (Table 3). Then, we evaluated the differences in these calculated insertion depths for the nonsubmerged and the submerged implants to see how much deeper the submerged implants were inserted compared to the nonsubmerged (Table 4). The value of the difference was positive when the result revealed a greater insertion depth for the submerged implants and negative if the insertion depth of the submerged implants was less deep. In this way, we calculated the following values: for the submerged implants of zirconia +0.47 mm, of coated zirconia −0.31 mm, of titanium +0.6 mm, and of PEEK +0.81 mm (Table 4). These findings contradict the statement of the authors that the submerged implants in general were inserted deeper than the nonsubmerged implants.

Another finding in the article states that the PEEK nonsubmerged implants showed significantly lower bone-related BL than the nonsubmerged coated zirconia and titanium implants (P = .046, .028). There is no evidence mentioned, if the mean insertion depths of the coated zirconia (2.56 mm), the titanium (2.02 mm), and the PEEK implants (1.74 mm) could play an influencing role for the bone-related BL, as the PEEK implants of the nonsubmerged group presented the lowest mean insertion depth (Table 3).

Neither of the 2 animal investigations observed inflammation signs or foreign body reactions, which emphasizes the evidenced biocompatibility of PEEK. Another in vitro study demonstrated attachment of a collagen gel to PEEK by enzyme-induced mineral deposition.38 If this kind of coating could be used to anchor a PEEK implant in the alveolar bone by collagen fibers like a natural tooth, this could represent another advantage of PEEK over titanium, giving back the physiologic tensile load to the bone.

**CONCLUSION**

Literature reporting on dental implants made from PEEK demonstrate that PEEK is basically osseointegrated as biocompatible material in vivo. Further investigations are necessary to find ways to improve the biomechanical behavior to achieve a more homogenous stress distribution to the surrounding bone, which has not yet been experimentally proven. Long-term investigations of loaded PEEK implants in vitro and in vivo are necessary. Experimental modulations of the surface are needed as well to achieve the highest possible grade of osseointegration. The design of a 2-piece implant made from PEEK, which allows the submerged healing method, has to be developed. PEEK used for a dental implant should have a light translucency similar to a natural tooth to achieve favorable esthetic results.

**ABBREVIATIONS**

BIC: bone-implant contact
BL: bone level
CFR-PEEK: carbon fiber–reinforced PEEK
PEEK: polyetheretherketone

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