Analysis of the effects of irradiation in osseointegrated dental implants

In the last years, osseointegrated implants have been used in dentistry for replacing missing teeth. Edentulous patients treated have a better quality of life and thus dental implants are becoming one of the major treatment modalities for oral rehabilitation.

However, the long-term success of these implants is related to osseointegration, which is defined as direct bone-to-implant contact (Chang et al. 2010). After implantation, the implant surface interacts with water, biological fluids and dissolved ions and the healing process initiates. According to the type of cells and their activities, two types of responses can occur: direct integration of the bone-implant without a connective tissue layer (osseointegration) or fibrous tissue capsule formation with clinical failure of the implant (Le Guehennec et al. 2004; Kurella & Dahotre 2005). However, according to Granstöm (2005) failure of osseointegration can occur due to other factors such as poor bone quality, traumatic surgical technique, overloading and also current diseases, smoking habits, ingestion of toxic drugs, osteoporosis and other causes.

In the last years, in vivo studies have evaluated the effects of radiation on the osseointegration of tissues after radiotherapy. Asikainen et al. (1998) studied the response around titanium implants inserted 2–3 months after the end of the irradiation phase. The authors concluded that with planning it is possible to achieve a high rate of success of osseointegration with radiotherapy.

Additionally, the effects of increasing doses of radiation on the biomechanics of implants 12 weeks after various doses (10, 20, 30 and 35 Gy) of irradiation were evaluated by Ohrem et al. (1977). Implants were inserted into rat tibiae after irradiation and after another 8 weeks these were tested mechanically in vivo. The authors verified significant reduction in torsion but the pull-out load was not significantly reduced for single doses up to 30 Gy. According to these authors, this value would correspond to approximately 50–70 Gy fractioned dose used in clinical practice.

Granstöm et al. (2005) evaluated patients who had received dental implants and were submitted to radiotherapy. The authors concluded that the presence of titanium implants can result in...
osteoradionecrosis and loss of the osseointegrated implant.

The effects of radiotherapy on bone remodeling around mandibular implants dogs were evaluated by Brasseur et al. (2006). Irradiation consisted of 10 daily fractions of 4.3 Gy 60Co. Implants were installed in dogs and two types of dental implants were used. Animals were irradiated 4 weeks after implantation and four others 8 weeks before implantation. In this study, was concluded that osseointegration can be obtained after irradiation, even when this later precedes implantation.

The purpose of our study was to evaluate the influence of irradiation on osseointegrated implants inserted into tibiae of rats by push-out test and histological analysis. A single dose of 30 Gy was used and this value was chosen based on Ohrnell & Branemark (1997) research.

Materials and methods

This research was approved by the Animal Bioethical Committee of the University of Taubaté. Twenty-four males Wistar rats [weighing 350–380 g] were used. During the experiment, rats were kept in cages with free access to food and water.

Animals were randomly divided into two groups of 12 animals. The experimental group (group 1) received external irradiation 4 weeks after surgery while in the control group (group 2) animals were kept free of radiation (rats were not paired after the groups’ formation).

Cylindrical implants (2.5 mm diameter and 3.5 mm of height) were custom made for this research. They were obtained from titanium bars (c.p. Ti) and after being manufactured were cleaned, blasted and sterilized.

Surgical procedure

Twelve hours before surgery, animals were fasted. Rats were anesthetized with an intramuscular injection of ketamine and xylazine (10 mg/kg). Two implants were inserted into each animal (one on the left tibia and the other on the right), which was a total of forty-eight implants.

For sterile preparation of the surgical site, the skin of rats was shaved and swabbed with povidone–iodine. Using sterile technique, a 10 mm incision was extended distally from the tibia tubercle and implants were inserted under saline irrigation to avoid overheating. Then, soft tissues were replaced and sutured with a 3–0 silk suture.

After surgery, animals were randomly divided into two unpaired groups, experimental and control group. Each group was divided into two subgroups: four rats were used for histological analysis and eight animals were used for biomechanical test.

Irradiation

For animals of group 1, 4 weeks after insertion of implants, rats were irradiated with single doses of 30 Gy. This value was chosen based on Ohrnell & Branemark (1997) research. The gamma irradiation was supplied by a 60Co source. Rats were anesthetized with an intramuscular injection of ketamine and xylazine (10 mg/kg). For each dose rate, four rats were irradiated simultaneously, and their bodies were protected by a lead jig (Fig. 1) while their legs received irradiation.

Rats were sacrificed by CO2 asphyxiation according to the schedule established for groups 1 and 2, 8 weeks after implantation (4 weeks after irradiation) and 4 weeks after implantation, respectively. Parts were dissected for histological analysis and tests were performed. Some animals died during healing time and after irradiation.

Histological and biomechanical analysis

For histological analysis, implants with surrounding tissue were removed and immersed in formaldehyde. Samples were embedded in polymethylmethacrylate and after polymerization cut with a saw, polished to a thickness of 180 μm and mounted on glass slides.

Table 1. Descriptive statistics of bond strength (MPa) after push-out test

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Experimental group (group 1) (30 days after irradiation)</th>
<th>Control group (group 2) (30 days after surgery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>33.49</td>
<td>48.05</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3.1</td>
<td>3.62</td>
</tr>
<tr>
<td>Median</td>
<td>33.66</td>
<td>48.77</td>
</tr>
<tr>
<td>Min</td>
<td>29.55</td>
<td>44.13</td>
</tr>
<tr>
<td>Max</td>
<td>37.07</td>
<td>51.26</td>
</tr>
</tbody>
</table>
were stained with Stevenel’s blue and Alizarin red stains for light microscopy.

For biomechanical testing, tibiae were placed into ice-cold PBS before the test. The samples were tested to evaluate the shear strength required to detach the implant from bone. Load was applied using a specially designed jig coupled to a Universal Test Machine with a constant displacement speed of 0.5 mm/min. The value of force to measure bond strength was determined when the peak force was reached. After testing, the surfaces of implants were evaluated using an optical microscope (Epiphot 200, Nikon, Yokohama, Japan).

The descriptive statistics of each group was calculated after biomechanical testing. The data were analyzed using the non-parametric Mann-Whitney test for independent data under the following hypotheses: $H_0: \mu_1 \leq \mu_2$; $H_1: \mu_1 > \mu_2$, where $\mu_1$ is the average of the experimental group (or group 1) and $\mu_2$ is the average of the control group (or group 2).

Results

The values obtained for the two groups are shown in Table 1. The value of push-out bond strength was significantly reduced after radiotherapy ($P<0.0259$) indicating that bond strength was higher for group 2 (control group, without radiotherapy).

Discussion

Currently, dental implants are widely used in prosthetics rehabilitation of patients over 50 years of age. However, there is a high incidence of cases of head and neck cancer for this age group. Radiotherapy is one of the most common treatments used in these cases. During treatment, irradiated bone changes properties, with loss of bone quality and vasculature. Additionally, the quantity of doses has been shown to be very important for bone recovery after treatment (Asikainen et al. 1998).

According to Brogniez et al. (2002), patients who have had increased tooth loss due to radiotherapy exhibit satisfactory rehabilitation from the use of dental implants. This result is directly related to radiation time and installation of the prosthesis (i.e., the longer the wait for rehabilitation, the greater the chance of success).

Generally, loss of the implants is increased in implants inserted in irradiated bones (McGhee et al. 1997; Wagner et al. 1998; Asikainen et al. 1998; Brogniez et al. 2002; Granstöm 2005). However, in vivo studies using animal models to evaluate the influence of irradiation on osseointegrated implants have not yet been performed.

In this work, the effect of radiation on osseointegrated implants was evaluated in vivo by comparing the biomechanical strength of implants from irradiated and non-irradiated rats. Implants were inserted in the tibia and after 30 days the rats were irradiated. Rats were sacrificed 30 days after irradiation. The surfaces of the implants after biomechanical testing were evaluated and significant differences in implant surfaces were observed. For non-irradiated implants (Fig. 2a), bone tissue between the thread of the implants was seen even after testing. However, irradiation resulted in an area without a trace of bone tissue after testing (Fig. 2b). These results confirm the values obtained in the tests and the decrease in the mechanical strength of the tissues.

The histological analysis confirmed these results (Fig. 3). For group 1 (irradiated), there was bone tissue in areas next to the screws, but necrosis areas were observed in more distant regions (Fig. 3a). Also, an absence of bone marrow that had necrosis after irradiation was observed. The loss of this tissue drastically reduced the shear strength of implants. From these results, we can conclude that there is a range of immature bone in threads of the irradiated implant next to a large area of necrotic tissue. For the control group (non-irradiated), bone exhibits a normal appearance and good contact with threads of the implant.

In Fig. 2, the surfaces of the implants after biomechanical testing were evaluated and significant differences in implant surfaces were observed. For non-irradiated implants (Fig. 2a), bone tissue between the thread of the implants was seen even after testing. However, irradiation resulted in an area without a trace of bone tissue after testing (Fig. 2b). These results confirm the values obtained in the tests and the decrease in the mechanical strength of the tissues.

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After irradiation, the average value of bond strength was 33.49 MPa (group 1), while for the group 2 (control group) the value was 48.05 MPa. We observed that the reduction in bond strength was close to 30%.

Images of the implants obtained by optical microscopy showed bone adhered to threads after testing of the specimens that had not been irradiated. In contrast, no bone was verified in irradiated samples. These results were confirmed in histological analysis. Non irradiated samples were well integrated with bone tissues while after irradiation was observed loss of bone tissues and necrosis in the irradiated regions.

Conclusions

Titanium dental implants treated by acid, implanted into rat tibia and treated with radiotherapy 30 Gy showed a reduction in the strength 30 days after radiation. Moreover, implants without irradiation showed an increase in mechanical strength thirty days after surgery.

We concluded that the mechanical strength of the bone–implant association is directly related to the quality of bone formation around the implant. Radiation therapy inhibits bone formation, which reduces mechanical strength. Therefore, the mechanical adhesion between the implant and the bone tissue decreases after irradiation. These results confirmed the negative effect of irradiation on osseointegrated implants.

References


