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Morphological and animal study of titanium dental implant surface induced by blasting and high intensity pulsed Nd-glass laser

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Abstract

Machined dental implants of titanium were blasted with Al_2O_3 powder of 250 μm particle size. The surface was irradiated in vacuum with a Nd-glass pulsed laser at 1–3 J pulse energies. The morphology of these surfaces was investigated by optical and scanning electron microscopy. The low intensity laser treatment resulted in some new irregularities but we can observe the blasted elements and caves from the original blasted surface too. The blasted elements were washed out and a new surface morphology was induced by the high intensity laser treatment.

The osseointegration was determined by measuring the removal torque in the rabbit experiments. The results were referred to the as machined surface. The blasting slightly increased the removal torque. The laser irradiation increased the removal torque significantly, more by a factor of 1.5 compared to the reference at high laser intensity. This shows the influence of the surface morphology on the osseointegration.

The combination of the blasting with the laser irradiation is considered a method to determine the morphology optimal for the osseointegration because the pulsed laser irradiation caused modifications of the micrometer sized surface elements and decreases possible surface contamination.

Keywords: Dental implants; Osseointegration; Laser surface treatment

1. Introduction

Titanium dental implants are widely employed. They have good osseointegration properties with predictable lifetime. The long-term benefits of such implants are caused by the responses of different surrounding tissues. These takes place on the bone–implant interface. The physiological process occurring at this zone primarily depend on three crucial characteristics of the implant surface, namely the cleanness, the micromorphology and the stable oxide layer formed on the implant surface. The surface contamination may of course originate from the bulk material of the implant, but in most cases it occurs during the procedure of surface treatment. It seems generally accepted that any contamination has unfavorable biological effects. The second important feature of implant surface is its micromorphology. Micromorphology generally means the irregularities on the implant surface less than 100 μm in size. It is generally accepted that the rough surfaces are better than smooth surfaces with regard to the osseointegration. The ideal surface morphology, however, is still unknown. Opinions on this issue are different and sometimes conflicting. Mechanical locking may be enhanced by an increase of the surface roughness and the stress distribution can be improved [1]. These positive effects must be balanced with the potential negative effects, e.g. a rough surface collect more bacteria than a smooth one and also increase the ion release [2].

The third important feature on implant surface is the natural oxide layer (8–10 nm) that forms immediately on the titanium surface when exposed to oxygen [3]. This oxide layer is the most important factor causing the biocompatibility of titanium.

Our motivation is to investigate the morphology of the machined, machined and Al_2O_3 blasted, machined Al_2O_3 blasted and laser treated surface. The surface cleaning and oxidation were hold constant by means of Al_2O_3 blasting and by pulsed laser melting in vacuum. We suppose that the

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bioinert Al_2O_3—which remained on the surface after blasting—did not disturb the cleanness of the implant. The goal of the paper is to show a correlation between surface morphology and osseointegration.

2. Experimental

Screw-shaped implants were made of commercially pure titanium (ISO 5832 Pt. 2 Grade 1) and sterilized by hot air flow (200 °C). The length and diameter of the implant was 8 and 3 mm, respectively, fitting the anatomical condition of the experimental animals. The screw thread region was complemented with a square-shaped part equally suitable for fixing and removing the implant and also for bearing a code necessary to perform the "blind test" study. The surface of the titanium implant was machined and blasted with Al_2O_3 powder of 250 μm particle size by means of 6×10^5 Pa compressed airflow. The original machined sample was used as the reference in this study.

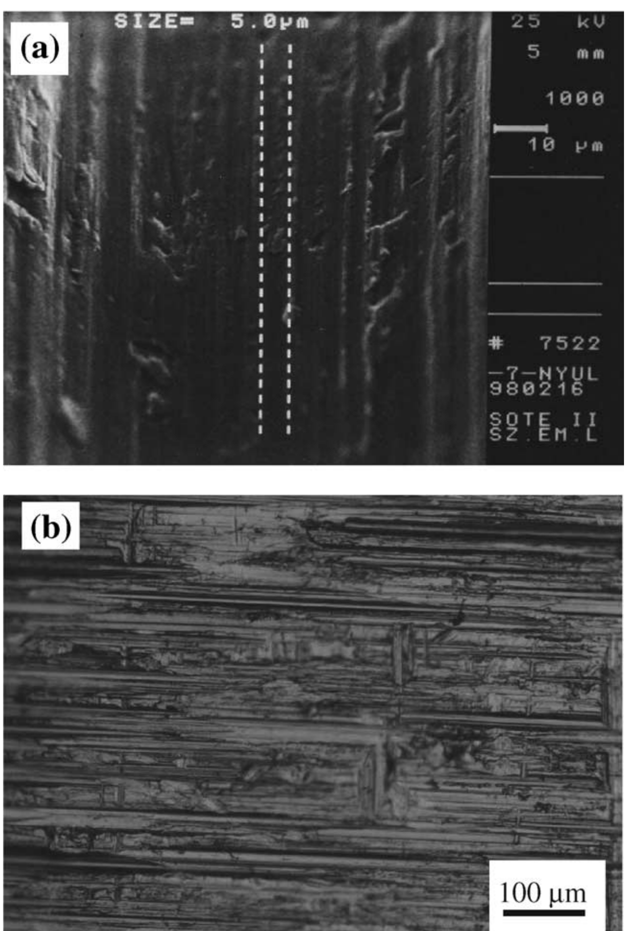

Fig. 1. Surface morphology of a machined titanium implant surface by SEM 1000 × magnification (a) and by optical microscope 100 × magnification (b).

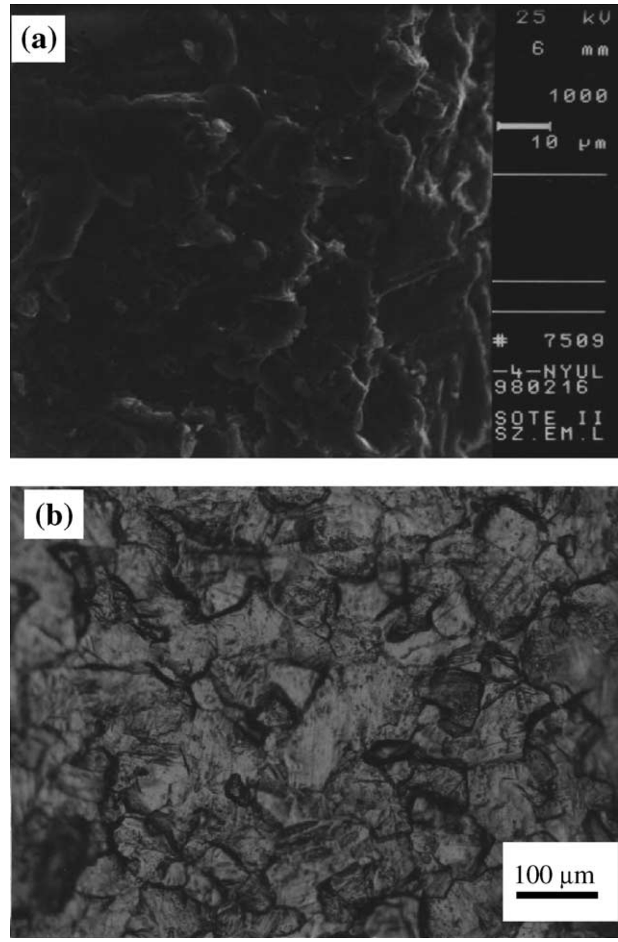

Fig. 2. Surface morphology of an Al_2O_3 sand blasted titanium implant surface by SEM 1000 × magnification (a) and by optical microscope 100 × magnification (b).

The laser treatment is carried out in 10^{-5} mbar vacuum by means of the focused light of a pulsed Nd-glass laser. The laser pulse hit the surface in a 2×3 mm^2 spot. There was no overlapping between the spots. The wavelength was 1054 nm, the pulse length was 30 ns and the pulse energy 1–3 J/imp, resulting in a power density of $2–6 \times 10^9$ W/cm^2. This results in a surface temperature higher than 5×10^3 °C. The surface of the implant melts during the period of energy irradiation. The melted zone is 40–50 μm in depth. Due to the high temperature the superficial layer, including the possibly surface contamination, will be ablated from the surface. The untreated internal mass of the implant—which is large, compared to the mass of the molten surface layer—cools down the superficial layer below melting point within several microseconds after the pulse of irradiation. The surface preserves its morphological irregularity at the final of the melted state. After the very fast cooling, the appeared dendritic crystals also enhanced the morphological variations. The modified morphology [4] strongly differs from the original morphology and has an enhanced cleanness too.

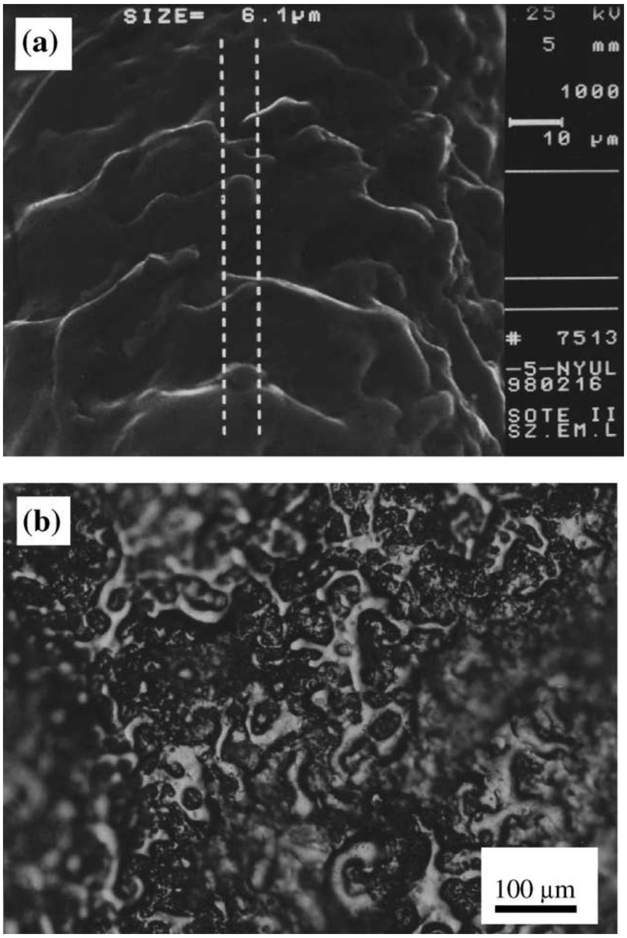

Fig. 3. Surface morphology of an Al_2O_3 sand blasted and 1 J laser irradiated titanium implant surface by SEM 1000× magnification (a) and by optical microscope 100× magnification (b).

The following samples were investigated, as:

1. Machined,
2. Sand blasted (250 μm),
3. Sand blasted + laser treatment (1 J),
4. Sand blasted + laser treatment (3 J).

The following is the description of the rabbit experiment: After the healing procedure, we measured the removal torque of implants placed in the rabbit femur. This technique serves as a general model in the experimental studies to investigate the extent of osseointegration. In this experiment, eight New Zealand albino rabbits with a mean body mass of 3.75 kg were used. Prior to the studies, the animals were anesthetized with 10% Nembutal (Phylaxia Pharma Rt., Hungary) injected intravenously via a cannula fixed in the ear vein. The femur was exposed through an approach from the incision made on the inner side of the thigh. Sockets for the implants were created in the femur by using auger, then spiral drill and thread cutter. The drilling was performed at low rotary speed in conjunction with physiological saline irrigation as cooling. The wound was closed by resorbable sutures (Vycril–Braun) after topical penicillin administration. The coded implants were randomly assigned for implantations in such a way that each animal received four implants with different surface treatments. The implants were resided in part in the compact bone and in part in the

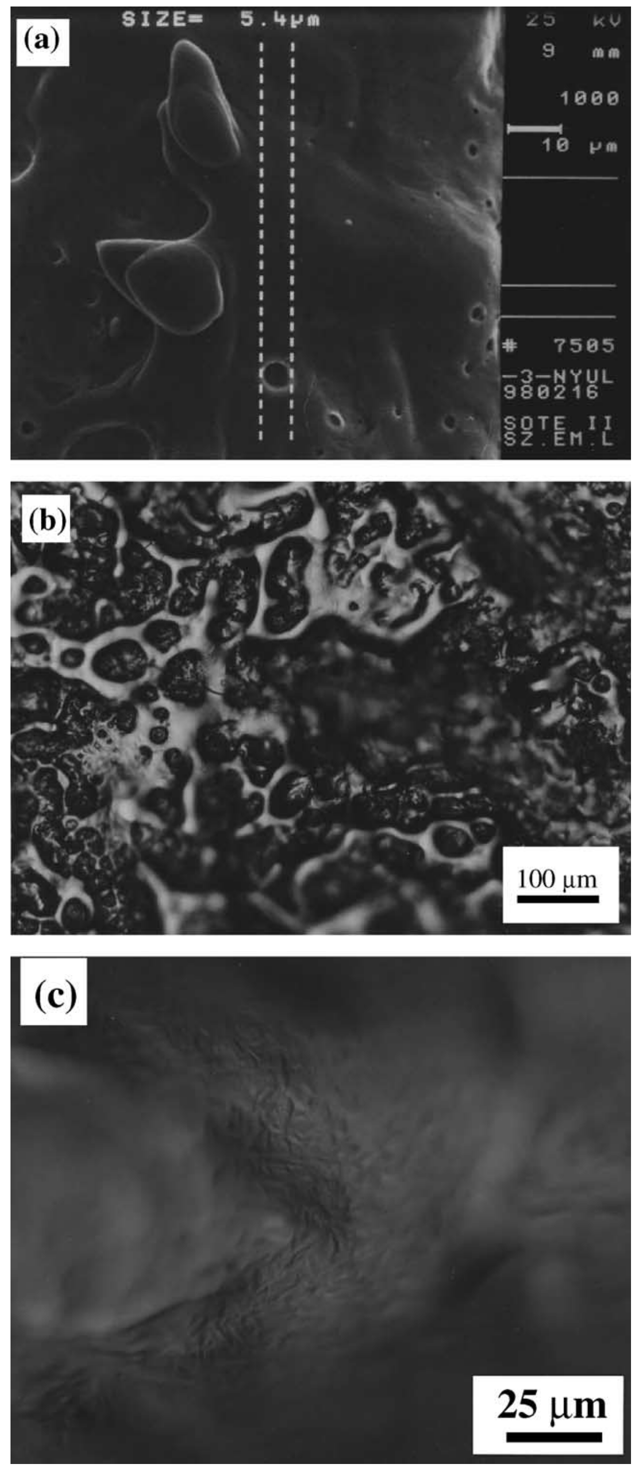

Fig. 4. Surface morphology of an Al_2O_3 sand blasted and 3 J laser irradiated titanium implant surface by SEM 1000× magnification (a) and by optical microscope 100× magnification (b), and 400× magnification (c).

medullary space in accordance with the anatomical conditions of the femur. In the postoperative period of 3 months duration, the rabbits were fed Furistar (Purina) to ensure the conditions for an uneventful recovery. Three months after surgery, the animals were perished by overdose of anesthetic. For the removal of the implants from the femur, reverse torque rotation was applied by using a titanium piece fitting exactly to the protruding part of the implant with a torque gauge interpositioned. In the torque gauge, the deformation of a steel spring due to the torque is transformed in an electric signal via an opto-electronic transmitter. This electric signal is read out from the display of an electronic instrument as a real time or maximum value (mV). The mV value read out from the display is correlated in a torque value (N cm) on the basis of a quasi-linear relationship, which was verified by means of a calibrator device where the torque was created using weights and length.

3. Results and discussions

The pictures which characterized the morphologies were obtained by electron microscopy with magnification of 1000 × (case "a"), and by optical microscopy with magnification of 100 × and 400 × (cases "b, c"). It can be observed that the machined surface is quite flat, having low density of defects resulting from the machining process (Fig. 1a,b). Blasting with 250 μm Al_2O_3 particles causes a homogeneously rough surface, the size of the elements is in the 5–50 μm range (Fig. 2a,b). Laser treatment significantly modifies the surface morphology for both 1 and 3 J energies.

The surface morphology can be distinguished to flat and patterned regions (Figs. 3b and 4b) and they are in different heights. The detailed morphology of the patterned region is visible in Figs. 3a and 4a. The morphological features differ in the 1 and 3 J laser treatment. In the first case, the surface is covered by elements of around 10 μm size or less, but with quite large surface density. In the second case, relatively large elements are visible on a flat background but with lower density. There are some holes of 1–5 μm size. These holes may originate from the blasting by the deep penetrating Al_2O_3 pearls.

It is necessary to mention that the Al_2O_3 embedded into the surface will be largely removed by the laser irradiation [5].

The ratio of the flat surface to the structured one is larger in 3 J laser energy treated sample case. Between the salient parts of the surface at the deeper regions, smaller and larger continuous areas with shapes of dendritic forms can be observed (Fig. 4c). The mean values and standard deviation (sd) of removal torque in the animal experiments are presented in Fig. 5.

The relatively large standard deviation of the results originated from several conditions influencing the experiments; the discrete character of each rabbit and each bone, the difference in the healing process, measuring errors, etc. Despite of the large deviation, it is clearly seen that the larger roughness of the blasted surface has positive effect compared to the machined sample. The laser treatment enhances this effect, proportionally to the pulse energy in the 1–3 J range. The 3 J laser treatment after sand blasting results in a remarkable 50% increase of removal torque. It is

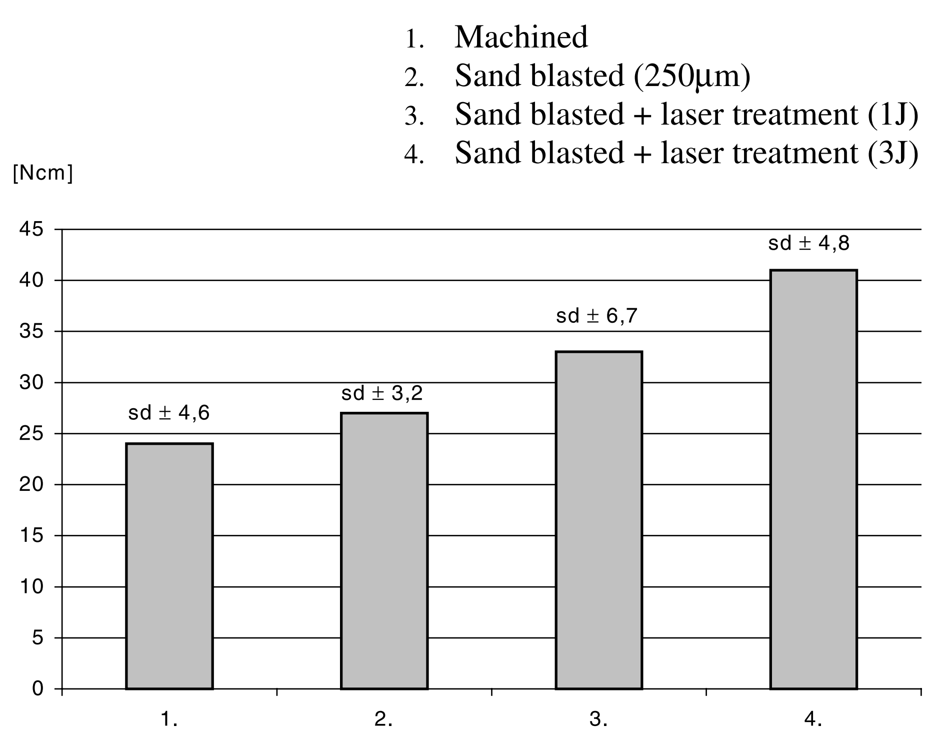

Fig. 5. Removal torque [N cm] data of different surfaces.

necessary to mention that the average roughness is largest at the blasted sample case. After laser irradiation, the roughness will decrease with increasing pulse energy. In the machined and blasted cases, roughness dependence of removal torque is the same as it is expected from published data [1]. In contrary to the blasted and laser irradiated cases, the dependence is in opposite, namely the removal torque increases with decreasing of the surface roughness. This observation can be explained by an enhanced cleanness of the surface or by formation of the morphological elements having size in 10–30 μm region. The cleaning process of laser irradiation should be already very effective in 1 J energy. On the other hand, the enhancement of removal torque is larger in 3 vs. 1 J irradiation than for blasted vs. irradiated sample with 1 J irradiation. These observations are making it unlikely that the reduced contamination is the dominant source of observed increase of osseointegration.

4. Conclusion

The treatment with Nd-glass laser pulses of the Al_2O_3 blasted titanium surface induced unique morphology characterized by morphological elements with sizes in 10–30 μm range. The formation of the 10–30 μm elements enhances more the osseointegration than the increase of the average roughness. The animal experiment shows that this combination of surface treatments produced a significant enhancement in removal torque, so it seems to be a promising technological process for preparation of the titanium dental implant surfaces.

Acknowledgements

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