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METAL AS BUILT ADDITIVE MANUFACTURING ROUGHNESS PARAMETERS EVALUATED TO BE USED AS INTRAOSSEOUS DENTAL IMPLANTS

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Abstract. *Intraosseous metal implants are used in dentistry to replace lost teeth and to function as artificial roots, where a dental prosthesis could be anchored. The phenomenon of bone tissue growth on the surface of the implant is known as osseointegration, and several strategies are used to improve osseointegration on dental implants, such as modifying surface roughness and increasing the implant surface energy. With the recent popularization of additive manufacturing / 3D printing, there is an increasing interest in the application of this technology on dental implant manufacturing since it offers several advantages such as the development of implants with customized design, porosity and roughness. In the present work, metal additive manufacturing flat surface roughness parameters are evaluated to be used as intraosseous dental implants without the use of posterior surface treatments. The roughness measurements were obtained using a mechanical contact profilometer. The results are compared with data provided in the literate for commercially available implants and show that additive manufacturing is suitable to be used in the dental context in relation to the surface roughness parameters. In addition, a great prospect of this proposal is the possibility of elimination of posterior surface treatments, allowing faster and cheaper production of these implants.*

Keywords: *additive manufacturing, 3D printing, dental implants, roughness, surface*

1. INTRODUCTION

The use of additive manufacturing processes in medical and dental intraosseous implants is a big tendency since it offers several advantages such as the generation of implants with customized design, porosity and roughness. In addition, the use of additive manufacturing generates an implant computer 3D model, which helps to plan the surgery, reduces time and improves medical accuracy (Javaid and Haleem, 2017).

This work objectives are to carry a literature review about the use of additive manufacturing surfaces as medical and dental implants and to analyze the roughness of a flat sample produced by additive manufacturing without posterior surface treatment. The experimental values will be compared with data reported in the literature for commercially available implants. The initial hypothesis is that additive manufactured implants can be used without surface treatments and the sample's roughness parameters are in appropriate values.

Every engineering surface presents errors in form and shape, regardless of how carefully this surface was prepared and manufactured (Williams, 2005). Roughness are variations found on engineering surfaces which have short wavelength and high frequency (Williams, 2005). There are many roughness parameters that can be analyzed, however, when measuring dental implant roughness, it is recommended to measure at least one height parameter, one space parameter and one hybrid parameter (Wennerberg and Albrektsson, 2000). For 3D measurements the suggested ones are S_a and S_q (height), S_{cx} and S_{tr} (space), S_{dq} and S_{dr} (hybrid). For 2D measurements the suggested ones are R_a and R_q (height), R_{Sm} (space), R_{dq} (hybrid) (Wennerberg and Albrektsson, 2000).

In the present work, the measured parameters were R_a, R_q, R_{Sm}, R_{sk}, R_{ku}, R_{dq}, where R_a, R_q, R_{sk} and R_{ku} are height parameters, R_{Sm} is a space parameter, and R_{dq} is a hybrid parameter. The definition of the parameters according to EN ISO 4287 are as follow:

R_a: parameter calculated as the arithmetic mean of the absolute values of the height of the irregularities, and it is the most commonly used parameter to characterize dental implant surfaces (Wennerberg and Albrektsson, 2000);

R_q: parameter calculated as the square root of the mean of the surface height values;

R_{Sm}: spacing parameter that is calculated as the average value of the width of the profile elements;

R_{dq}: hybrid parameter representing the mean square slope of the evaluated profile;

R_{sk}: parameter known as skewness and represents the symmetry of the profile, that is, when a profile is symmetrically distributed with as many peaks as valleys, it presents zero skewness, whereas a profile with many high peaks has positive skewness and with deep valleys has negative skewness (Gadelmawla et al., 2002);

R_{ku}: parameter known as kurtosis and represents the sharpness of the distribution curve, when the kurtosis is smaller than 3, the distribution curve is flattened and the surface presents few high peaks and low valleys, when the kurtosis is greater than 3, the profile presents many high peaks and low valleys (Gadelmawla et al., 2002).

Commercially available dental implants are manufactured by machining pure titanium or the Ti-6Al-4V alloy. After machining, the implants go through different surface treatments, such as sandblasting, grit-blasting and acid etching (Tunchel et al., 2016). These surface treatments have been developed in order to improve osseointegration, decrease healing time and improve implant stability, since surface characteristics such as roughness, energy and chemical composition influence cell growth mainly in the early stages of osseointegration (Elias, 2011). Also, a porous structure that replicates the biomechanical properties of the surrounding bone is important to promote bone growth into the implant metal structure, accelerating the integration processes (Wang et al., 2016).

It is reported that smooth surfaces ($S_a < 1$ µm) show less osseointegration than rough surfaces. Some studies have suggested that moderately rough surfaces (1 µm $< S_a <$ 2 µm) have better adhesion to bone tissue than rough surfaces ($S_a > 2$ µm). However, most of the published articles have made an inadequate characterization of the implant surface roughness using only height parameters instead to use hybrid and space parameters as well (Wennerberg and Albrektsson, 2009). S_a is the 3D surface roughness parameter equivalent to R_a.

Elias et al. (2008) investigated the roughness and contact angle of machined dental implants with different surface treatments. In vivo tests have suggested that the surface treatments have benefited the biocompatibility of implants. On the other hand, Li et al. (2012) manufactured titanium alloy Ti-6Al-4V implants using additive manufacturing and controlling the internal structure of the pores. In vivo and in vitro tests were performed with these implants, separated into two groups: with and without a surface layer of apatite. Bone growth into the implants structure with and without apatite was similar.

Bertollo et al. (2012) compared in vitro tests of additive manufactured implants and implants with plasma coated titanium coating. No significant differences were found. Biemond et al. (2013) also performed comparative tests using implants produced by two different selective laser melting techniques (SLM and electron beam melting or EBM) with and without calcium phosphate surface coating. The tests were performed on goats and no significant difference was found. Matouskova et al. (2018) performed in vitro tests and measured the roughness of titanium samples produced by additive manufacture. The parameter R_a was checked. The sandblasted sample had R_a equal to 3.4 µm, while the sample without surface treatment presented R_a equal to 13.3 µm. However, in vitro tests showed better cell growth in the sample without surface treatment.

Tunchel et al. (2016) manufactured dental implants of titanium alloy powder (Ti-6Al-4V) using 3D printing technology. The dental implants were fixed in 82 patients and in total, 110 implants were installed, 65 in the maxilla and 45 in the mandible. Patients were then observed for 3 years and at the end of the study 6 implants failed, generating a success rate of 94.3%. Tunchel et al. (2016) concluded that, considering the results obtained, additive manufacturing techniques are a viable option in the production of dental implants, and they do not require post fabrication decontamination and surface treatments.

Additionally, the printing parameters of the additive manufacturing process have influence on the roughness of the final sample. It is reported that the roughness parameter R_a varies between 1 and 20 µm, depending on the choice of printing parameters and sample thickness (Safdar et al., 2012).

These studies suggest that porous additive manufactured implants can be used without surface treatments, whereas traditional machined implants require these treatments.

Several studies have shown the potential of additive manufactured implants. However, there is still no comparison with traditional implants (Mangano et al., 2014). Moreover, it does not seem to be consensus on an ideal roughness value for dental implants.

2. MATERIAL AND METHODS

The roughness parameters of a flat sample produced by additive manufacture were evaluated in this study. The measurement of roughness of flat surfaces is relevant in this context since implant manufacturers use flat disks to characterize the processes and tests of cell growth (Naves et al., 2015). The roughness measurements were obtained following the guidelines published by Wennerberg and Albrektsson (2000) and a mechanical contact profilometer.

The sample was 3D printed using EOS M Eosint 280 printer (Fig. 1), which uses selective metal laser sintering to make ready-to-use parts. The material used was stainless steel identified by PH-1 supplied by the company EOS. The sample was cleaned using clean acetone and ultrasonic bath. The sample dimensions are 5 mm x 35 mm x 50 mm.

Figure 1. EOS M Eosint 280 3D printer (Marzano, 2015)

A portable mechanical contact profilometer Surtronic 3+ 112/1590 model, manufactured by Taylor Hobson, with a diameter of 2 µm was used to evaluate roughness. Thirty measurements were taken perpendicular to the main direction of the irregularities with evaluation length of 12.5 mm and cut-off of 2.5 mm. The measured parameters were R_a, R_q, R_{Sm}, R_{sk}, R_{ku}, R_{dq}, where R_a, R_q, R_{sk} and R_{ku} are height parameters, R_{Sm} is a space parameter, and R_{dq} is a hybrid parameter. The evaluation was taken at 20ºC and 1atm pressure.

Figure 2 is a photo taken from the sample captured using a scanning electron microscope. The black lines added show the perpendicular direction to the main direction of the irregularities, in which the measurements were performed. Figure 3 shows the experimental apparatus.

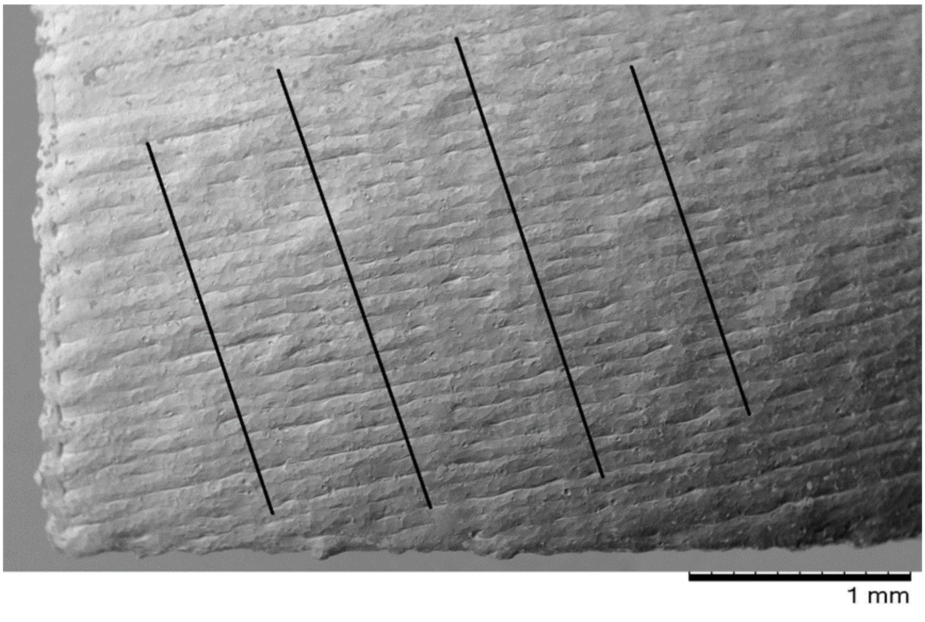

Figure 2. Superficial image of flat sample taken using a scanning electron microscope. The black parallel lines are used as references for the perpendicular direction in relation to the irregularities

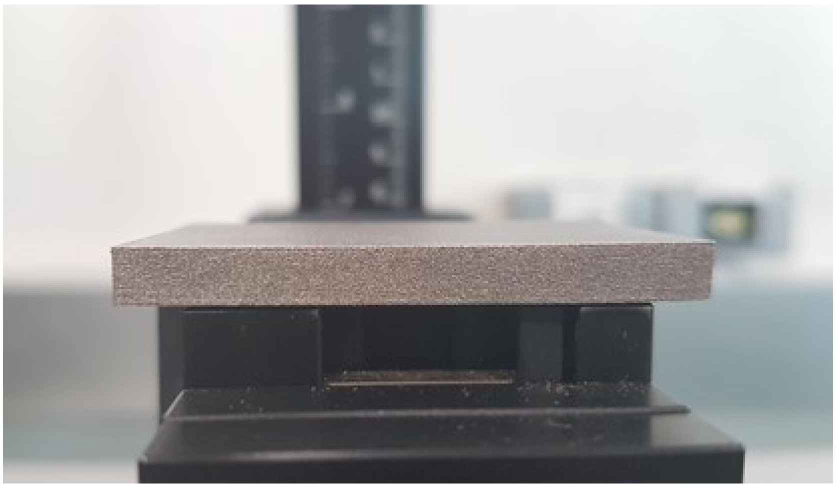

Figure 3. Experimental apparatus: flat sample's overview positioned on a support

3. RESULTS AND DISCUSSIONS

In the present work thirty roughness measurements were performed. The roughness measurements are perpendicular to the main direction of the irregularities and the parameters R_a, R_q, R_{Sm}, R_{sk}, R_{ku}, R_{dq} were evaluated. The mean and standard deviation of the thirty roughness results were calculated and they are shown in Tab. 1. The comparison between the results obtained experimentally and the data found in the literature is depicted in Tab. 2.

Table 1: Mean roughness parameters values of thirty measurements carried out in the perpendicular direction from the main direction of the irregularities.

Parameter	Mean results	Standard deviation
R_a [µm]	4.55	0.35
R_q [µm]	5.64	0.44
R_{Sm} [mm]	0.235	0.025
R_{sk}	-0.0714	0.2376
R_{ku}	3.74	0.66
R_{dq} [degrees]	12.9	1.0

Table 2: Roughness comparison between experimental data and the results found in the literature, such as the percentage differences between them.

	Experimental data	Barbosa (2016)	Dif % – Barbosa (2016)	Naves et al. (2015)	Dif % – Naves et al. (2015)	Wennerberg and Albrektsson (2000)	Dif % – Wennerberg and Albrektsson (2000)
R_a / S_a[µm]	4.55	1.06	329%	1.23	270%	2.12	50%
R_q / S_q[µm]	5.64	1.35	318%	1.58	257%	Not evaluated	-
R_{Sm} / S_{cx}	0.235 mm	Not evaluated	-	Not evaluated	-	17,85 µm	-
R_{sk}	-0.0714	Not evaluated	-	-0.08	11%	Not evaluated	-
R_{ku}	3.74	Not evaluated	-	3,75	0%	Not evaluated	-
R_{dq} / S_{dq} [degrees]	12,9	Different unity	-	Different unity	-	Not evaluated	-

Comparing the experimental data with values reported in the literature by Barbosa (2016), Naves et al. (2015) and Wennerberg and Albrektsson (2000), it was possible to observe that the parameters Skewness and Kurtosis presented values close to the normal distribution curve in both cases (literature and experimental data), the R_{Sm} value of the experimental data differed from those found in the literature, it was not possible to compare the parameter R_{dq}, and the parameters R_a and R_q presented experimental values higher than the literature.

The parameter R_a (the most used parameter to describe the surface of dental implants) found for the sample was 50%, 270% and 329% higher than that described in the literature for commercial dental implants. However, the roughness results allow the use of additive manufacture in dental implants without the need for posterior surface treatment, since rough surfaces improve osseointegration (Wennerberg and Albrektsson, 2009).

One limitation of this study is that the surface parameters were not experimentally measured in the final geometry of the implant. However, it is believed that the experimental data found can be extrapolated to an implant generated by the same printer, using the same material and the same printing parameters. Although in vitro and in vivo tests were not performed in this work, the roughness data obtained experimentally and the literature suggest that posterior surface treatments can be eliminated from the implant manufacturing process if additive manufacturing is used, allowing faster and lower production costs of these implants.

No comparative studies have been found up to the present moment of dental implants manufactured by additive manufacturing processes and conventional dental implants. This is an essential point that will be treated in future studies.

4. CONCLUSIONS

This study objective was to investigate the feasibility of using 3D printing techniques in dental implant manufacturing without the need for posterior surface treatments. The flat evaluated sample demonstrated the characteristics of a rough surface, being the parameter R_a higher than the values described in the literature for commercial dental implants.

Therefore, the present work reinforces the studies that have already been reported in the literature showing the feasibility of the use of as built additive manufactured dental implants. The advantages of using this technology are the generation of implants with customized geometry, roughness and porosity, besides helping to plan the surgery, reducing time and improving medical performance. It is believed that in this context the posterior surface treatments can be removed from the dental implant manufacturing process, allowing faster, easier, and cheaper production of more suitable dental implants.

5. ACKNOWLEDGEMENTS

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