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*Original Article*

# Surface topography of sandblasted and acid-etched titanium implants with different macrogeometric characteristics

*Artigo Original*

# Topografia de superfície de implantes de titânio jateados e condicionados com ácido com diferentes características macrogeométricas

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Keywords:
Dental implants; Surface roughness;
Implant surfaces.

## Abstract

*Objectives:* This study aimed to understand the influence of implant macrodesign over the topography and roughness of implants and to investigate the level of control in the treatment process. *Materials and Methods:* Implants of different designs and produced in two distinct companies (Neodent and Straumann) were analyzed at different positions and sections. The quantitative analyses were performed using an optical interferometer and the qualitative assessments utilized SEM. The evaluation parameters were Roughness Average (Ra), Peak Density (PD), and I Surface Area Ratio (ISAR). *Results:* There were no qualitative differences among implants of the same company, with different macrodesigns, but differences were seen between companies. The highest values for Ra were seen in the Neodent implants. In comparing the implants according to section for Ra and ISAR, the Neodent implants differed little among each other, but many statistically significant differences were seen between the Neodent and Straumann implants. In comparisons of implants × sections × thread positions, values for Ra were similar between the Neodent implants and differed from the Straumann implants. For PD, in the neck and apex sections no statistically significant differences in the flank position were seen in any of the implants. For ISAR, few differences were seen between the interactions evaluated. When evaluated individually in the same positions and different sections, the Straumann implants showed a higher homogeneity of surface treatment. *Conclusions:* When implants of different designs were considered separately (Alvim, Drive, Titamax, and Straumann), standardization was observed for the studied parameters (Ra, PD, and ISAR) in the sections and positions evaluated. Implant surface analysis should consider implant different designs and threads shapes as these parameters influence topography results.

## Resumo

Objetivos: Este estudo teve como objetivo compreender a influência do macrodesenho do implante sobre a topografia e a rugosidade dos implantes e investigar o nível de controle no processo de tratamento. Materiais e Métodos: Implantes de diferentes desenhos, produzidos em duas empresas distintas (Neodent e Straumann), foram analisados em diferentes posições e secções. As análises quantitativas foram realizadas utilizando um interferômetro óptico e as avaliações qualitativas utilizaram MEV. Os parâmetros de avaliação foram Rugosidade Média (Ra), Densidade de Pico (PD) e Razão de Área de Superfície (ISAR). Resultados: Não houve diferenças qualitativas entre os implantes da mesma empresa, com diferentes macrodesenhos, mas diferenças foram observadas entre as empresas. Os maiores valores de Ra foram observados nos implantes Neodent. Ao comparar os implantes de acordo com a secção para Ra e ISAR, os implantes Neodent diferiram pouco entre si e diferenças estatisticamente significativas foram observadas entre os implantes Neodent e Straumann. Nas comparações de implantes × secções × posições da rosca, os valores de Ra foram semelhantes entre os implantes Neodent e diferiram dos implantes Straumann. Para PD, no pescoço e no ápice, não foram observadas diferenças estatisticamente significativas na posição do flanco em nenhum dos implantes. Para ISAR, foram observadas poucas diferenças entre as interações avaliadas. Quando avaliados individualmente nas mesmas posições e em diferentes secções, os implantes Straumann apresentaram uma maior homogeneidade do tratamento de superfície.

Palavras-chave:
Implantes dentários,
Rugosidade superficial,
Superfícies de implantes

Conclusões: Quando implantes de diferentes desenhos foram considerados separadamente (Alvim, Drive, Titamax e Straumann), observou-se padronização para os parâmetros estudados (Ra, PD e ISAR) nas secções e posições avaliadas. A análise da superfície do implante deve considerar diferentes desenhos e formatos de rosca, pois esses parâmetros influenciam os resultados topográficos.

## Introduction

Oral rehabilitation using osseointegrated implants leads to a real and perceptible improvement in chewing, consequently increasing quality of life for edentulous patients[1]. This has also proven to be a predictable method for replacing missing teeth with several potential prosthetic solutions, both fixed and removable. There is a large amount of scientific evidence showing the success of these implants using a wide variety of surgical protocols [2; 3; 4; 5].

One important feature of titanium is the immediate formation of a layer of oxides 2 to 7 nm thick, which causes the biomaterial to meet oxygen[6]. This layer of oxides promotes adsorption of proteins and chemotaxis of cells, resulting in osseointegration; in this dynamic process, the mechanisms of the host interact to integrate with the implant material[7].

Modifications of implant surfaces are consequently crucial to the short-term and long-term success of dental implants[8] and may alter the response at the bone/implant interface[9]. To increase success rates, the surfaces of titanium implants have frequently been studied to obtain better performance from this material when it is in contact with bone cells, consequently providing longer-lasting treatments and reducing the time patients need to wait before prosthetic rehabilitation can begin[10]. Consequently, some methods to create ridges and modifications on the titanium surface (such as addition and subtraction) are being developed. Studies have shown that better mechanical stability of the implant as well as the prosthesis can be obtained in the long term when implants with rough surfaces are used instead of smooth surfaces[11; 12; 13].

Furthermore, macrogeometry and thread configuration are also important to osseointegration. Design is one of the factors that directly affect primary stability of an implant and its ability to support loads after osseointegration, and together with the shape of the body of the implant and the thread pitch affect the interface between bone and implant loads[9].

The SLA surface manufactured by Straumann (Basel, Switzerland) has been shown to promote differentiation of osteoblasts, increase cytokine synthesis and growth factors involved in osteogenesis, and consequently provide better bone-implant contact than smooth surfaces[14]. Neodent (Curitiba, Brazil) is an example of an implant company that produces fixtures with a SLA type surface in implants with different designs.

Considering the importance of macro - and microgeometry in dental implants and the need to establish parameters of surface roughness for osseointegration, the objective of this study was to assess the surface topography and effectiveness of implants with different macrogeometry produced by one implant company; it was compared the flank, valley, and top positions of the threads in the neck, mid-body, and apex sections of implants with the same surface treatment manufactured by an international reference in the production of these implants.

## Materials and Methods

### *Sample Groups*

Four units each (from different lots) of Alvim, Drive, and Titamax implants made by Neodent were obtained. One implant of each type underwent ultrastructural analysis in the scanning electron microscope (SEM), and three of each type was analyzed using the interferometer. For reference and comparison, three Straumann Bone Level Crossfit implants (SLA surface, Roxolid) from the same lot were used for analysis in the interferometer (Figure 1).

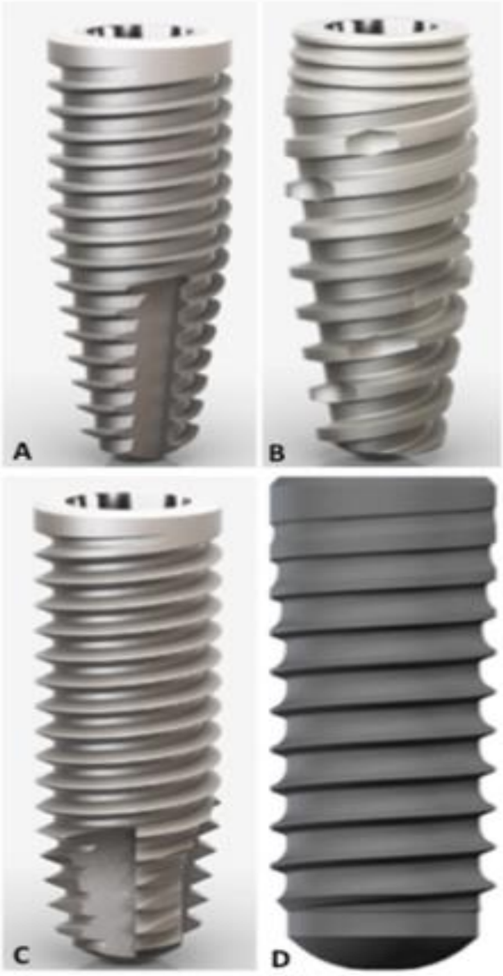


Figure 1. Implants used in the study: A – Alvim tapered-body implant with compacting, dual trapezoidal threads; B – Conical Drive central-core implant with dual progressive threads and smaller neck section in relation to the implant body; C – Cylindrical Titamax implant with pyramid-shaped double self-cutting edges; D – Straumann cylindrical Bone Level implant with reverse buttress threads and square neck.

### *Analysis of Surface Treatment*

#### *Qualitative Assessment*

For qualitative analysis of the superficial topography obtained with the surface treatment, a FEI QUANTA FEG 250 scanning electron microscope (Instituto Militar de Engenharia, Rio de Janeiro, Brazil) was used. A sample from each of the implants in the neck, mid-body, and apex sections of the implant was analyzed.

#### *Quantitative assessment*

Quantitative characteristics of the implant surfaces were assessed using a Mirau white light optical interferometer (Zygo New View 7100, Middlefield, USA) with a 50x lens coupled with an internal 0.75x magnification lens. A Gaussian high-pass spline filter (50 × 50 μm) was selected to separate three components: shape, undulations, and roughness. The surface to be evaluated was carefully perpendicular to the light source and ensure that the most accurate measure possible was obtained for roughness. The interferometer data were processed using MetroPro software (Zygo Corporation, Middlefield, USA) and the parameters of roughness were calculated.

For numerical characterization of the implant surfaces using the interferometer, it was measured the neck, mid-body, and apex sections of each implant (dividing the implant equally into thirds) in the top, flank, and valley positions of the threads. Three measurements were taken around each third of the implant to obtain mean values for assessment. For each implant, 27 measurements were taken, 81 for each group of three implants, and 324 measurements for all twelve implants. It has been chosen to analyze different lots of the Neodent implants to assess the regular nature of the surface treatment procedure between the implants studied, and identical lots of the Straumann implants which were used for comparison. The implants were analyzed in their commercial state, without prior treatment. Each drawing of the implant shows the characteristic macrogeometry and the specific thread format (Figure 2).

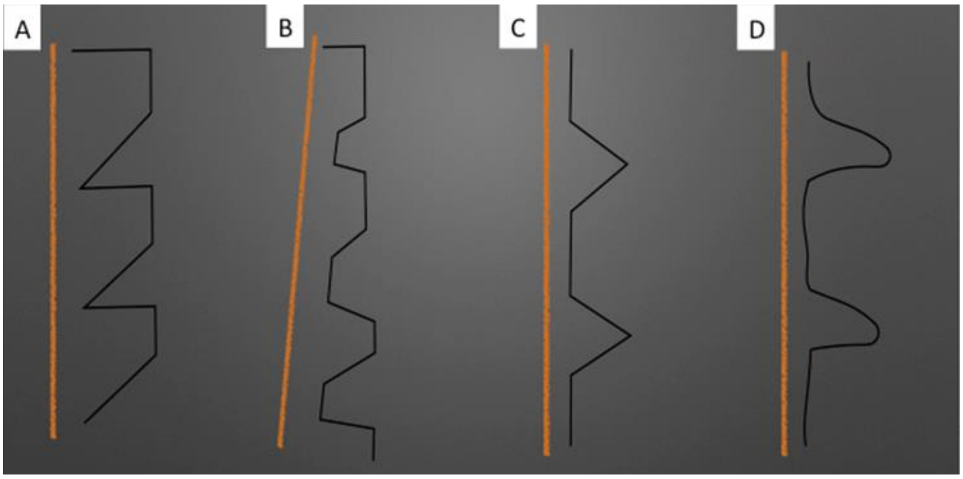


**Figure 2.** Thread anatomy of each implant: A – Trapezoidal threads, Alvim implants; B – Progressive threads, Drive implants; C – Pyramidal threads, Titamax implants; D – Reverse buttress threads, Bone Level implants.

For quantitative description of the surface topography using the interferometer, we used the following parameters:

a) **Roughness Average (*μm*) (Ra*):*** represents the arithmetic mean of the height of the peaks and depth of the valleys, the surface roughness in the median plane;
b) ***Peak Density* (*1/mm*) (PD):** represents density, in other words the number of peaks per unit area;
c) ***I Surface Area Ratio* (*%*) (ISAR):** hybrid parameter that represents the increase of area obtained.

The analyses were performed in triplicate for each region and position for each implant evaluated.

***Statistical analysis***

The statistical analyses were performed using SPSS 23.0 software and three-way ANOVA. Normality was verified by the Shapiro-Wilk test, using a 5% significance level. Tukey's HSD multiple comparison test was used to assess homogeneous variances and the Games Howell multiple parameter comparison test was used for heterogeneous variances. The homogeneity of variances between the treatments was verified using the Levene test. Pearson's correlation coefficient was also used to establish the statistical correlation between the parameters Ra, PD, and ISAR

## Results

***Qualitative analysis (SEM)***

Analysis of the surface of the Alvim (Figure 3 A), Drive (Figure 3 B), Titamax (Figure 3 C), and Straumann (Figure 3 D) implants in randomly selected regions of the implant revealed regions of peaks and valleys spread across the surface, as well as characteristics of a surface treated with sandblasting and acid etching.

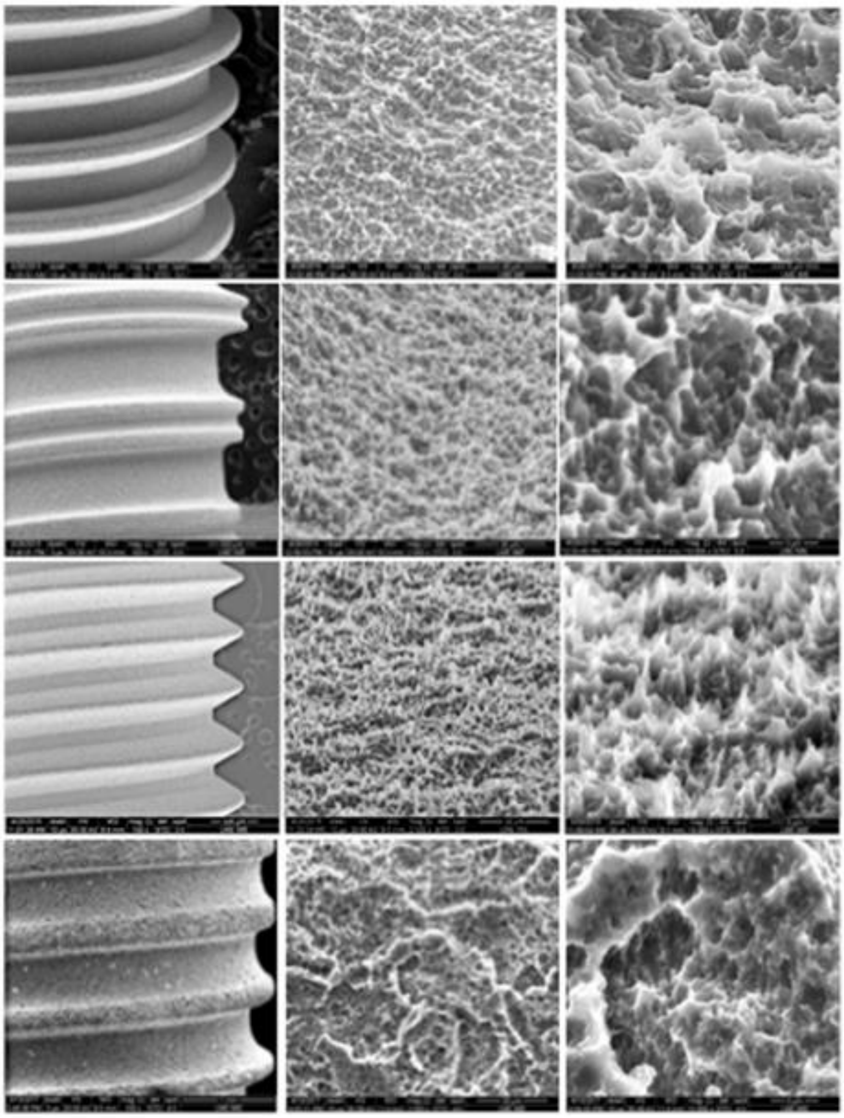


**Figure 3.** Representative scanning electron micrograph of the Alvim (A), Drive (B), Titamax (C) and Bone Level (D). Magnifications: A=100×; B= 2.500×; C= 10000×.

***Analysis of the studied parameters in relation to the three sections of the implants***

The mean values for the parameters Ra, PD, and ISAR in the different sections of the Alvim, Drive, Titamax, and Straumann implants are shown in (Table 1). We found that the Straumann implants had the lowest values for Ra (0.60 µm ± 0.11) compared to the others ($p < 0.05$), regardless of which section of the implant was assessed. No statistically significant differences for Ra were seen in any of the Neodent implants in any of the three sections, but they did differ from the Straumann implants, with the exception of Titamax, which was similar to the Straumann implant in the apex section. The values for the parameters PD and ISAR were greater in the Straumann implants, with an average of 9048 ± 3360 (1/mm) and 158% (± 60), respectively, mainly in the apex section. For PD and ISAR, the Drive implant demonstrated a statistical difference in the neck section when compared to the other Neodent implants and the Straumann implants. For PD in the mid-body and apex sections, no statistically significant differences were found among the Neodent implants, but they all differed from the Straumann implants. For ISAR, a statistical difference was only seen in the apex section, where all the Neodent implants statistically differed from the Straumann implants.

Table 1. Description of the values for the implants in the neck, mid-body, and apex sections and the mean values and standard deviations for the parameters studied by interferometry in the macrostructure of the implants. PD = Peak Density; ISAR = ISurface Area Ratio; NS = neck section; MS = mid-body section; AS = apex section; OM = overall mean. Different letters indicate statistical differences among the implants for each parameter evaluated ($p < 0.05$).

| | | Alvim | Drive | Titamax | Straumann |
|---|---|---|---|---|---|
| RA (µm) | NS | 0.90 (0.14) a | 0.88 (0.11) a | 0.78 (0.15) a | 0.53 (0.09) b |
| | MS | 0.88 (0.15) a | 0.81 (0.15) a | 0.78 (0.16) a | 0.61 (0.11) b |
| | AS | 0.86 (0.11) a | 0.83 (0.15) a | 0.76 (0.21) ab | 0.65 (0.10) b |
| | OM | 0.88 (0.13) a | 0.84 (0.14) a | 0.77 (0.17) b | 0.60 (0.11) c |
| PD (1/mm) | NS | 5256 (1693) a | 3164 (1121) b | 6582 (3720) a | 6858 (2417) a |
| | MS | 4777 (1322) b | 5581 (3415) b | 6068 (3132) b | 9157 (2571) a |
| | AS | 3770 (884) b | 5038 (2975) b | 6051 (3791) b | 11128 (3578) a |
| | OM | 4601 (1464) a | 4594 (2855) a | 6234 (3524) b | 9048 (3360) c |
| ISAR (%) | NS | 119 (27) a | 85 (22) b | 117 (32) a | 127 (29) a |
| | MS | 117 (28) a | 119 (55) a | 118 (37) a | 162 (66) a |
| | AS | 100 (21) b | 118 (61) b | 98 (19) b | 186 (65) a |
| | OM | 112 (27) a | 107 (51) a | 111 (31) a | 158 (60) b |

***Analysis of the studied parameters in relation to the three sections and positions of the implants***

For the different thread positions (top, flank, and valley), differences were seen in relation to the three sections for each implant evaluated (Table 2). For the parameter Ra in the neck section, no statistical differences were seen at the top or flank position in the various Neodent implants, but there were differences between the Neodent and Straumann implants. At the valley position, the Titamax and Alvim implants exhibited differences between each other, and the Alvim and Drive implants differed from the Straumann implants. For PD in the neck section, the tops, flanks, and valleys had equal values in comparison between the Neodent and Straumann implants, with some differences between the Drive and the other Neodent implants in the top and valley positions. This also occurred for ISAR in the neck section, but no differences were seen among the Neodent implants at the top. In the mid-body section, for the parameter Ra no differences were seen among the implants in the top position; for the flank, differences were seen between the Neodent and Straumann implants as well as differences in the valley between the Alvim and Straumann implants. For PD at the top of the middle-body section, the only difference was found between the Alvim and Straumann implants, as well as on the flank between the Titamax and Straumann implants. In the valley position, the only statistical similarity was between the Titamax and Alvim implants. For ISAR in the middle-body section, the top, flank, and valley demonstrated similarities between the four implants, except between the Alvim and Titamax implants, which were not statistically different from the Straumann implants. In the apex section, for the parameter Ra the top and valley positions of the threads were statistically equal in all implants evaluated. For PD, the Alvim and Drive implants were equal, as were the Titamax and Straumann implants at the top and flank of the threads. For ISAR, the flank exhibited statistically equal values for all the implants, and the top and valley were equal among the Neodent implants and different when compared to the Straumann implants.

Table 2. Mean values (SD) for the implants evaluated in the neck section, in the top, flank, and valley position for the parameters studied. PD = Peak Density; ISAR = ISurface Area Ratio; NS = neck section; MS = mid-body section; AS = apex section; OM = overall mean. Different letters indicate statistical differences among the implants for each parameter evaluated ($p < 0.05$).

| | | Ra (µm) | | | | PD (1/mm) | | | | ISAR (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Alvim | Drive | Titamax | Straumann | Alvim | Drive | Titamax | Straumann | Alvim | Drive | Titamax | Straumann |
| NS | Top | 0.80 (0.13)a | 0.83 (0.09)a | 0.71 (0.10)ac | 0.60 (0.07)bc | 6619 (1328)ab | 3683 (1737)a | 11033 (2427)b | 6820 (2066)ab | 104 (12)a | 92 (31)a | 115 (16)a | 131 (22)a |
| | Flank | 0.87 (0.10)a | 0.97 (0.13)a | 0.95 (0.09)a | 0.49 (0.08)b | 5350 (1710)a | 3190 (548)a | 4688 (2188)a | 6734 (2917)a | 155 (10)b | 89 (20)a | 150 (25)b | 117 (27)ab |
| | Valley | 1.02 (0.06)a | 0.86 (0.03)ab | 0.68 (0.10)bc | 0.51 (0.08)c | 3800 (390)a | 2619 (256)b | 4024 (783)a | 7019 (2483)ab | 97 (4)b | 74 (5)a | 85 (11)ab | 134 (37)ab |
| MS | Top | 0.78 (0.12)a | 0.74 (0.08)a | 0.70 (0.12)a | 0.65 (0.05)a | 5681 (873)a | 5494 (1858)ab | 9790 (2524)ab | 7889 (1029)b | 99 (6)a | 97 (26)ab | 105 (14)a | 142 (13)b |
| | Flank | 1.01 (0.11)a | 0.97 (0.17)a | 0.97 (0.06)a | 0.62 (0.13)b | 5111 (1420)ab | 8626 (3744)ab | 4200 (1316)a | 9013 (2176)b | 155 (98)a | 183 (45)a | 165 (22)a | 157 (30)a |
| | Valley | 0.84 (0.10)a | 0.72 (0.06)ab | 0.68 (0.11)ab | 0.55 (0.10)b | 3540 (367)b | 2623 (399)c | 4215 (641)b | 10570 (3407)a | 97 (6)a | 76 (12)a | 86 (9)a | 188 (109)a |
| AS | Top | 0.77 (0.08)a | 0.75 (0.09)a | 0.60 (0.09)a | 0.69 (0.08)a | 3941 (556)b | 4387 (1607)b | 10596 (3142)a | 9208 (1460)a | 85 (6)a | 85 (16)a | 91 (10)a | 156 (17)b |
| | Flank | 0.97 (0.09)a | 1.00 (0.14)a | 1.02 (0.11)a | 0.57 (0.09)b | 4138 (1280)a | 8179 (2726)a | 3640 (1186)a | 9903 (4005)a | 126 (13)a | 193 (51)a | 116 (20)a | 148 (25)a |
| | Valley | 0.83 (0.05)a | 0.74 (0.06)a | 0.67 (0.09)a | 0.70 (0.06)a | 3231 (284)ab | 2549 (450)a | 3916 (720)b | 1427 (2543)c | 90 (8)a | 78 (16)a | 86 (12)a | 253 (71)b |

### *Comparison among the three sections and positions on the same implant*

The comparison among the three sections and positions on the same implant are demonstrated in Tables 1 and 2.

The Alvim implants showed no statistically significant differences in the Ra values in the top and valley positions in the neck, mid-body, and apex sections. No statistically significant differences were seen between the top, flank, and valley positions in the neck, mid-body, and apex sections. For PD there were statistically significant differences between the top and valley positions in the neck and mid-body sections. The apex section exhibited statistical differences from the mid-body and neck sections in the top position. For ISAR, there were statistically significant differences between the flank and valley positions in the neck, mid-body, and apex sections. There were also statistically significant differences between the apex, mid-body, and neck sections in the flank position.

For Ra in the flank position, the Drive implants differed statistically from the top and valley positions in the mid-body and apex sections. No statistically significant differences were seen between the top, flank, and valley positions in the neck, mid-body, and apex sections. For PD, statistical differences were seen between the flank and valley positions in the apex section and between the neck and apex sections in the flank position. For ISAR, there were statistically significant differences between the flank and the top and valley positions in the mid-body and apex sections. There were also statistically significant differences between the neck and the mid-body and apex sections in the flank position.

In the Drive implants, Ra in the flank position differed statistically from the top and valley positions in the neck, mid-body, and apex sections. No statistically significant differences were seen between the top, flank, and valley positions in the neck, mid-body, and apex sections. For PD, statistically significant differences were seen between the top and the valley and flank position in the neck and mid-body sections. There were no statistically significant differences between the neck, mid-body, and apex sections in the top, flank, and valley positions. For ISAR, the flank and valley positions in the neck and mid-body sections differed from each other. The mid-body section also showed a statistically significant difference between the top and flank positions. There were also statistically significant differences between the mid-body and apex sections in the flank position.

For Ra, the Straumann implants did not differ statistically between the top, flank, and valley positions in the neck, mid-body, and apex sections.

There were statistically significant differences between the neck and apex sections in the valley position. For PD, statistically significant differences were seen between the flank and valley position in the mid-body section. Significant differences were also seen between the neck and apex sections in the valley position. For ISAR, no statistically significant differences were seen between the sections and positions.

## Discussion

The objective of this study was to analyze the surfaces of implants of different designs and thread shape, treated with sandblasting and acid etching by evaluating the NeoPoros surfaces produced by Neodent with demonstrated clinical outcomes[4;15] and comparing these surfaces with a gold-standard surface with the same surface treatment[16], Straumann's SLA. Three parameters of surface roughness were evaluated: Ra is the arithmetic mean in relation to the height of the peaks and depth of the valleys; Peak Density (PD) represents the density of the peaks, and ISurfAreaRatio (ISAR) is a hybrid parameter that represents the total increase of area obtained. These parameters are in agreement with the study suggested by Wennerberg A and Albrektsson T to standardize the procedures for topographic assessment of implant surfaces[17]. The parameter Ra is not always useful for describing the morphology of a given area but is used because no other surface roughness parameter is better for describing and predicting the behavior of an implant. Even so, doubts remain as to whether the height of the irregularities is more important than the distance between them, and what combination of these factors may improve osseointegration[18].

The surface roughness of the neck, mid-body, and apex sections of the implants in the top, flank, and valley positions were evaluated for the three parameters. This analysis is necessary because from the moment implants are installed, the top and part of the flank of the thread are in close contact with the bone and marrow tissue, permitting contact osteogenesis and consequent formation of "new" bone"[19]. The valley position of the thread is where blood clots remain and it is known that bone formation occurs from the host bone, moving toward the titanium. This is how distance osteogenesis occurs, with a population of osteogenic cells that first establish a new bone matrix. In this case, bone remodeling takes longer to occur, since the area needs to be invaded by osteoclasts that remove necrotic bone before it is colonized by osteogenic cells [19]. Successful fixation may depend on how quickly this osteogenesis occurs[18]. Fast and strong bone formation provides better stability during the healing process and allows the implant to bear load more quickly[17], also preventing bone resorption[8].

In order to classify the surfaces in a quantitative manner, it were compared the mean values obtained for the entire surface of the implants. For the parameter Ra, the Straumann implants yielded the lowest values with an average of 0.6 µm, unlike previous findings[20], and the highest values for Ra were found in the Neodent implants, which were 0.8 µm as found previously[21], but for the three-dimensional parameter Sa. Three-dimensional parameters are more accurate, realistic, reliable, and representative[17], but two-dimensional parameters are accepted as long as 25 measures of each implant are taken 20 µm apart, perpendicular to the direction of the irregularities[17]. These requirements were followed in this study and took 81 measurements in each group of three implants. Despite the statistically significant differences in Ra, all the implants in this study were within the range classified [22] as minimally rough (Sa: 0.5–1.0 µm), with results for surface roughness proven in the literature as biologically acceptable for sandblasted and acid-etched dental implants [14; 23].

In the statistical analysis, the Pearson correlation coefficient showed a significant degree of association between the parameters PD and ISAR. This indicates that as the density of peaks of the surface increases the area for future bone-implant contact also increases. The density of the peaks was inversely proportional to height and was greater in the Straumann implants and lesser in the Neodent implants. Consequently, the total area of contact obtained by the surface analysis and represented by the parameter ISAR increased an average of 158% for the Straumann implants, while for the Neodent implants the increase was around 110%. The values for Sdr, a parameter that represents the three-dimensional increase in the surface as a percent, were found to be 143% in one study[24] for SLActive surfaces and 199% for anodized surface implants[21].

When this parameter of roughness approaches 50%, there is good bone-implant contact (BIC) and stable union, increasing the chances of maintaining the osseointegration in the long term[13; 14]. Some studies show that greater full-surface contact may improve favorable clinical outcomes because it determines the osteocondutive potential of the implant surface[25;26]. Other studies show that osteoblast adhesion to the implant surface alone is not sufficient to ensure osseointegration, because the cells need to receive signals inducing them to proliferate[18; 24; 27].

The variations in height and number of peaks and valleys on the implant surfaces may be related to the degree of hardness of the titanium used by the company, the type, size, and impact speed of particle during sandblasting, and the type of acid, and temperature and time of exposure [21]. The SLA surface is blasted with particles ranging from 0.25 to 0.5 mm in size under controlled pressure of 5 bar and then subjected to acid etching[28]. The NeoPoros surface uses oxides with controlled particle sizes and pores varying from 2.5 to 5 µm. SEM imagery shows the regularity of the process and differences in the NeoPoros and SLA surfaces.

The Neodent implants showed no significant differences in Ra when compared with each other in the neck, mid-body, or apex sections. All three Neodent implants had higher mean values and differed significantly from the Straumann implants in this comparison, except for the neck section, in which no significant differences were seen between the Titamax and Straumann implants. For PD in the neck section, the Drive implant had lower values with statistically significant differences from all other implants in the same section. In the mid-body and apex sections, no differences were seen among the Alvim, Drive, and Titamax implants, but the Straumann implants showed higher mean values. For ISAR, the lowest values for the neck section were seen for the Drive implant and were statistically different from all the other implants. In the mid-body section for this same parameter, the implants were all equivalent; for the apex section, the Straumann implants differed from the Neodent implants, which in turn were similar to each other.

Although some statistical differences were seen when the same sections in the different implants were compared, more statistically different areas were found when sections (neck, mid-body, and apex) and positions (top, flank, and valley) were also compared, since the number of evaluated areas was multiplied. The differences found may result from the fact that when the macrostructure of a given area is altered, its micrometric characteristics may also change [14; 24] considering the different formats of the implant threads. There were no statistical differences between the Neodent implants for the parameter Ra in comparison with each other in the top and flank positions of the neck section or in the top, flank, and valley of the mid-body and apex sections; however, a number of differences were observed in comparison with the Straumann implants. For this parameter, the major differences between the Neodent and Straumann implants were seen in the flank position of the neck section. For PD, in the neck and apex sections no statically significant differences in the flank position were seen in any of the implants. In the other areas a number of differences were seen in section and position between the Neodent and Straumann implants. For ISAR, the Drive differed from the Alvim and Titamax implants in the neck-flank regions, and the Drive and Alvim implants differed in the neck-valley regions. For the other comparisons, differences were seen between the manufacturers when they occurred.

In order to understand the level of control in the surface treatment process for each implant, these treatments were evaluated individually. When analyzed and compared separately, they exhibited homogeneity in the treatment process, but this homogeneity was not absolute, especially when the same position in different sections was compared. It was noted that for the Neodent implants, the few differences which were found in the interaction described were found for the parameters PD and ISAR. The top, flank, and valley positions are blasted at the same velocity during surface texturization but receive the blasts from different angles. This may explain the large differences between positions in the same section. The Straumann implants demonstrated greater similarity across their surfaces for the three parameters evaluated. In the comparison between same position in the different sections, it was noted a statistically significant difference between the neck and apex sections for the valley position in the Straumann implants for the parameters Ra and PD, and mean values were always lower in the neck section. The only significant difference between different positions in the same section in the Straumann implants was seen between the flank and valley positions in the mid-body section.

Another point to consider is that primary implant stability between 25 and 45 N.cm at the time of installation is very important for osseointegration[29] and depends on surgical technique, the geometry of the implant, and the bone density at the implant site [30]. Consequently, the secondary stability of the dental implants aided by the surface treatment is also important for cases in which implants cannot be stabilized immediately after installation[31]. Furthermore, texturing interacts with the components of the tissue adjacent to the implant, increases the speed and amount of osteogenesis, and increases longevity, which is a very important factor as life expectancy increases.

Even though the surface plays an important role in stability and osseointegration, some studies show that when bone quality is favorable, the surface occupies a secondary role, since more positive effects of surface roughness have been observed in low-density bones [9].

In this context, the influence of surface roughness is understood on a micrometric scale. Additionally, understanding the biology behind the implant is of utmost importance, because it opens doors for what should guide the development of solutions in this field, setting aside heuristic methods and replacing them with techniques that produce solutions to achieve a specific biological goal[7].

## Conclusion

When implants of different designs were considered separately (Alvim, Drive, Titamax, and Straumann), standardization was observed for the studied parameters (Ra, PD, and ISAR) in the sections and positions evaluated. Implant surface analysis should consider implant different designs and threads shapes as these parameters influence topography results.

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