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Comparative analysis of surface topography of custom CAD/CAM zirconia abutments by means of optical profilometry

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Abstract

Objective: CAD/CAM generated ceramic implant abutments have recently attracted interest due to their superior customization possibilities and aesthetic advantages. Despite their widespread clinical use, little information is currently available on their surface topography, however. The transmucosal portion of the abutment shoulder is of particular interest, as it ideally supports soft tissue but minimizes mechanical plaque retention. The aim of this *in vitro* study was to topographically characterize the trans- and subgingival roughness of CAD/CAM zirconia abutments from different manufacturers and compare them with zirconia stock abutments.

Material and Method: The surface topography of eight CAD/CAM zirconia implant abutments (tests) and two prefabricated zirconia stock abutments (controls) was determined using focus variation microscopy. Two points on the abutment shoulder were subjected to profilometric examination. 2D and 3D parameters of roughness were obtained and compared.

Results: The surface roughness of all the test abutments exceeded the recommended threshold of Ra = 0.2 µm and therefore exhibited an increased risk of mechanical plaque retention. Obvious differences in surface structure were apparent, allowing conclusions to be drawn about the manufacturing method and subsequent reworking processes.

Conclusion: Manually reworking the trans- and submucosal area of the investigated CAD/CAM zirconia abutments appears necessary to fulfil the conditions for optimal surface topography. The Sa value as arithmetic mean, taking the maximum height (Sz value) and surface excess (Sdr) into account, is an essential parameter for assessing the surface topography of implant abutments.

Key words: CAD/CAM abutments, zirconia, surface roughness, soft tissue adhesion, focus variation microscopy.

Introduction

An intact soft-tissue transition zone between the oral cavity and peri-implant bone is crucial for the long-term prognosis of an implant restoration.[1] Since implant abutments are a part of the superstructure that is in direct contact with peri-implant tissues, their biocompatibility, material structure, surface quality, and shape influence the soft-tissue reaction directly.[2,3] Recent developments in the area of computer-aided design and manufacture (CAD/CAM) enable fabrication of custom implant abutments made of titanium and zirconia ceramic. Custom CAD/CAM abutments allow correction of axial divergence between the implant and corresponding crown. The line of the crown margin can be adjusted to the line of the soft tissue, and the requirement for an anatomic emergence profile and controllable cement gap in a single implant-supported restoration can be met individually.[4-6]

Because of the biocompatibility and minor color change in the peri-implant mucosa, CAD/CAM abutments made of zirconia are used increasingly in the aesthetically important anterior region.[7,8] In addition to the different possibilities for connecting the implant and abutment, it is possible to use prefabricated stock- or individually milled CAD/CAM zirconia abutments, both of which today are available in one- and two-piece designs.[9-11] One-piece abutments, including the connection geometry, are milled entirely using the CAD/CAM process. Two-piece (hybrid) abutments consist of a prefabricated titanium adhesive base to which a custom CAD/CAM zirconia sleeve produced in the laboratory is bonded. For optimal results, the surface morphology of custom zirconia abutments should promote soft-tissue adherence while at the same time minimizing plaque retention in order to avoid inflammatory processes. Accordingly, high demands must be made of the surface quality of such abutments. The initial bacterial adhesion of the trans- and submucosal abutment surface is directly dependent on its surface roughness.[12] Studies confirm that a roughness of Sa= 0.2 µm can be accepted as a threshold; significantly exceeding this promotes the risk of mechanical plaque retention.[13] However, roughness should not be critically below this threshold to facilitate soft-tissue adherence and avoid loss of attachment.

Homogeneous, structure polished zirconia surfaces are regarded as biocompatible and plaque-resistant. They form the foundation for optimal soft-tissue adaptation and prevent bacterial adhesion.[8,14,15] Under periprosthetic, functional and hygiene aspects, the structure and morphology of the abutment surface represent a crucial criterion for the long-term success of an implant restoration.[16-19] To date there is no reliable information regarding the effect on peri-implant soft tissue of the surface quality, topography, and roughness of CAD/CAM zirconia implants produced industrially or in the laboratory. Minimal standards on the degree of roughness and microgeometry that may be adequate or necessary for healthy soft-tissue adaptation have not yet been developed. Prefabricated standard implant abutments usually follow a defined production protocol to meet established quality criteria.[20] Whether custom CAD/CAM abutments meet comparable quality criteria is not currently known.

The aim of the present study was therefore to characterize the surface topography of the trans- and submucosal zone of CAD/CAM zirconia ceramic abutments following processing and delivery by means of profilometry (focus variation microscopy).

Material and Method

For this *in vitro* study, eight CAD/CAM zirconia abutments produced by different manufacturers (test abutments) (samples 1-8; Fig. 1) were compared with two prefabricated zirconia stock abutments (control abutments) (samples 9 and 10; Fig. 2). The following CAD/CAM systems and brands were used:

Test abutments

One-piece zirconia abutments

Sample 1. Atlantis (Dentsply Implants, Mannheim, Germany): CAD/CAM zirconia abutment including connection geometry for Astra OsseoSpeed implant.

Sample 2. Bego CADAbut (Bego Medical, Bremen, Germany): CAD/CAM zirconia abutment including connection geometry for Semados implant.

Sample 3: BellaTek (BIOMET 3i, Florida, USA) CAD/CAM zirconia abutment including connection geometry for 3i implant.

Sample 4. Cares (Institut Straumann AG, Basel, Switzerland): CAD/CAM zirconia abutment including connection geometry for Straumann Bone Level implant.

Sample 5. Compartis (Dentsply Degudent, Hanau, Germany): zirconia abutment including connection geometry for Ankylos C implant.

Sample 6. Procera (Nobel Biocare, Zürich, Switzerland): CAD/CAM zirconia abutment including connection geometry for Nobel Active Implant.

Two-piece zirconia abutments (hybrid abutments)

Sample 7: Dedicam (Camlog GmbH, Wimsheim, Germany): CAD/CAM zirconia sleeve on titanium insert with connection geometry for CAMLOG implant.

Sample 8: Zfx (Zimmer Dental GmbH, Freiburg, Germany): CAD/CAM zirconia sleeve on titanium insert with connection geometry for Zimmer implant.

Control abutments

Sample 9: Astra ZirDesign (Dentsply Implants, Mannheim, Germany): prefabricated zirconia stock abutment including connection geometry for Astra OsseoSpeed Implant.

Sample 10: Ankylos Cercon Balance C (Dentsply Implants, Mannheim, Germany): prefabricated zirconia stock abutment including connection geometry for Ankylos C implant.

Sample production

For the present study, the master model came from a clinical case in which an implant restoration had replaced the left maxillary central incisor. The emergence profile of the peri-implant mucosa had been conditioned by a temporary implant supported single crown. Eight replicas of this master model were made in plaster, and each was adjusted in a parallelometer so that the planned implant analogs from the different manufacturers could be aligned in the same vertical and horizontal position. This ensured that the fabrication conditions for the CAD/CAM abutments were identical despite different connection geometries.

After drilling a central hole in the planned implant position, the corresponding implant analog from each respective manufacturer was positioned and plastered. Eight master models were therefore produced in which the relationship of the implant shoulder to the emergence profile was identical. To ensure that the abutment samples from different CAM systems on different implant types were comparable, a standardized wax-up of the abutment was made of try-in resin (with eight different connection geometries) (Figs. 3a & b). The specifications for the outer geometry of the one- and two-piece CAD/CAM abutments were identical and designed so that the planned crown margin was just below the mucosa and followed its anatomically curved line (Figs. 4 a & b). For the one-piece CAD/CAM abutments, the different manufacturers were commissioned to produce a custom zirconia abutment, taking the emergence profile into account. For the two-piece hybrid abutments, the adhesive surfaces of the titanium inserts and zirconia sleeves were gritblasted in the laboratory (aluminum oxide particles 50µm; 2 bar/ 0.25 MPa; 20 seconds; distance 10 mm) and cleaned with alcohol. The titanium inserts were then moistened with a metal primer solution (GC MetalPrimer II, GC EUROPE N.V, Leuven, Belgium), while a bonding material (Monobond Plus, Ivoclar Vivadent GmbH, Schaan, Liechtenstein) was applied to the basal parts of the CAD/CAM zirconia sleeves. All hybrid abutments were bonded with a composite cement (Multilink Hybrid Abutment, Ivoclar Vivadent GmbH, Schaan, Liechtenstein) in the laboratory, according to the manufacturer's instructions. Excess adhesive was then removed, followed by polishing of the luting joint with silicone polishers and polishing paste.[9] The zirconia stock abutments of the control group (Astra ZirDesign and Ankylos Cercon Balance C; both from Dentsply Implants, Mannheim, Germany) were removed from the manufacturer's original packaging and underwent profilometric examination immediately.

Profilometry

Profilometry was performed by means of a focus-variation system (Infinite Focus Standard G4, Alicona Imaging GmbH, Graz, Austria), in which form and roughness can be measured in one procedure. Focus-variation microscopy is a method for contact-free measurement of surfaces using optical devices with a low depth of focus. Depending on the surface topography, only limited regions are shown sharply, while the object being examined is scanned vertically. The actual depth can be found for each measurement point through differences in the depth of focus and the distance at which a certain measurement point is shown in sharp focus. With this system, surfaces in the micrometer and nanometer range can be measured. Two-dimensional (2D) and three-dimensional (3D) representations are possible. However, 2D measurement does not always suffice to describe the functionality of a surface exactly, especially if the surface has randomly distributed structural elements. To obtain a 3D representation, the depth of focus is obtained for each position on the object. When all measured points are included, the change in these values results in a graphic surface relief of the investigated implant abutment. This is an area-based method.

Experiment design

The zirconia test abutments first underwent macroscopic visual inspection. The emergence profile, shoulder line, and overall impression were evaluated. For microscopic examination, two measurement points on the trans- and submucosal part of the abutment surface were defined, both of which were in the region of the biological width. The first measurement point was on the labial side of the abutment, 2mm below the prosthetic shoulder. The second measurement point was on the palatal side of the abutment, 1mm below the prosthetic shoulder (Fig. 5).

The emphasis in the profilometry was on 2D and 3D measurement of the surface roughness. To evaluate this, the raw measurement data signals were first processed technically. The surface of the abutment was broken down into single points that delivered information about the surface form and waviness. The first step was to remove the form via a so-called F operator and then the short-wave deviations via a low-pass filter (S filter). With the resulting S-F surface, the form deviations and waviness, which, unlike roughness, give low-frequency signals, are removed via a special high-pass filter (L filter). The different parameters of roughness could then be calculated from the resulting S-L surface. The mean roughness (Ra) and total height of the roughness profile (Rt) were determined from the 2D measurement as amplitude parameters. The spatial parameters obtained from the 3D measurement were the mean surface roughness (Sa), the maximum height of the selected surface (Sz), and the relative rough surface (Sdr). Before performing the actual measurement, the form deviation of the selected implant abutment was reduced to one surface by using a third- and fourth-order polynomial calculation (cubic and quadratic function). The threshold wavelength lambda C was then set to 250 µm. Values with a greater wavelength were regarded as waviness and were filtered out by a special high-pass

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filter. A 20x lens was used in the subsequent measurements. (For technical details see Table 1.) This yielded a measurement area with a height of 0.544 mm and width of 0.715 mm. Two contiguous areas were measured per side. Since the macroscopic shape of the different test abutments showed pronounced differences in the subgingival region, some of the areas to be measured were positioned one on top of the other and some next to each other. The segment for determining the R values (Ra, Rt) was drawn vertically through the established area and corresponded to the red line in Fig. 6. The S values (Sa, Sz, Sdr) were obtained from the total area comprising the individual areas.

Results

Figures 7 through 10 display the true- and false-color images of the labial and palatal sides of the eight test abutments. Tables 1 through 9 present the findings for Ra, Rt, the Ra/Rt ratio and difference, Sa, Sz, Sdr, and the Sz/Sa ratio and difference. Table 10 summarizes all the 2D and 3D measurements.

Discussion

The surface structure and roughness of the marginal implant neck and their influence on the adaptation of the peri-implant soft tissue are the subject of numerous studies.[15,21-23] Studies of the surface structure of stock or CAD/CAM customized zirconia implant abutments, however, are only fragmentary.[24,25] The aim of the present study, therefore, was to characterize the surface topography of the trans- and submucosal zone of CAD/CAM zirconia ceramic abutments by means of focus-variation microscopy. The surface topography was usually assessed through the parameters of form, waviness, and roughness, with form, also called the profile, representing the coarsest and roughness the finest unevenness. Waviness and roughness are often combined under the term texture.[2]

The accuracy of roughness determination depends on the degree to which errors of the form and waviness parameters can be removed. However, there is still no generally accepted standard as to where the parameter of roughness ends and waviness begins. Wennerberg and Albrektsson have proposed guidelines on the topographic analysis of roughness and microgeometry for the standardized examination of titanium implants.[26] They classify implant surfaces with Sa values of 0.5-1.0 µm as smooth, Sa values between 1-2 µm as moderately rough, and Sa values over 2 µm as rough. How useful this classification is for ceramic implant abutments also depends directly on the range of roughness to be found in vivo.[27]

Six of eight CAD/CAM test ceramic abutments -- 3i BellaTek (0.43 µm), Ankylos Compartis (0.46 µm), Camlog Dedicam (0.63 µm), Zimmer Zfx (0.79 µm), Straumann Cares (0.89 µm) and Astra Atlantis (0.9 µm) -- demonstrated a Sa value of less than 1 µm. These Sa values correspond to a smooth surface, according to Wennerberg and Albrektsson's classification, which was proposed in principle for endosteal implant surfaces. By contrast, the Procera abutment was in the rough surface range, with an Sa value of 2.22 µm. Whether the Procera abutment involved a single case or whether the greater roughness can be attributed to the manufacturing process could be only partially explained by a systematic examination of the series, as each determination of roughness always refers only to a limited part of the total surface. With its mean Sa value of 0.33 µm, the Bego Semados abutment ranked between the two prefabricated abutments (Ankylos Cercon 0.25 µm and Astra ZirDesign 0.39 µm). All investigated CAD/CAM implant abutments exceeded the roughness threshold of Ra = 0.2 µm proposed by Bollen et al. for abutment surfaces[13] and thus showed an increased risk of mechanical plaque retention. (The prefabricated Ankylos Cercon abutment came closest to this value with an Ra value of 0.24 µm.) The results demonstrate that further manual processing of the transmucosal area of the tested CAD/CAM zirconia abutments in the laboratory would be essential to meet the conditions for optimal surface quality.

Recent data have thrown into question the reliability of Ra values for determining the surface roughness of implant abutments. Instead the Sa value has become established as the basis for assessing surface roughness. However, this is a mean that does not permit a conclusion about the maximum heights or depths of the surface and the frequency of their occurrence. The Sz and Sdr values can deliver additional information. As the present investigations show, the maximum heights of the measured surface (Sz value) range from 7.1 times (Astra Atlantis) to 15 times (Camlog Dedicam) the arithmetic means of the Sa. The Nobel Procera abutment, with a 9.4-fold value, was also in this range. The difference (with the exception of the Nobel Procera at 18.6 µm) between maximum height (Sz) and arithmetic mean (Sa) was between 3.1 µm (Ankylos Cercon) and 8.8 µm (Camlog Dedicam). Since the maximum height can also be influenced by impurities on the surface, its validity can only be evaluated to a limited degree. The Sdr value of a surface should therefore be included when assessing it. This represents the relationship of the excess of the true area to the projected area as a percentage. This value can provide evidence about the frequency of unevennesses (heights and depths) when additional information is available from the Sz value.

It was seen that the prefabricated Astra ZirDesign abutment, with an excess of 0.89% (Sa 0.39 µm, Sz 4.93 µm), was markedly over the excess of many other abutments, with greater Sa and Sz values. The Camlog Dedicam abutment, by contrast, had an Sdr of only 0.49% (Sa 0.63 µm, Sz 9.42 µm). It can therefore be assumed that there was a greater frequency of unevennesses in the tested Astra ZirDesign abutment. Comparison of the different roughness parameters shows that statement of a single parameter has only limited validity as regards the surface texture. The Sa value as arithmetic mean possibly represents the most important parameter for assessment. To obtain a more detailed overview of the surface characteristics, however, inclusion of the maximum height (Sz) and area excess (Sdr) appears useful. Consequently, assessment of the surface roughness of ceramic abutments (SRCA) should include the parameters Sa, Sz, and Sdr. A guide to assessment of the surface roughness of ceramic abutments might look like Table 12.

With the aid of focus-variation microscopy, too, evidence about the possible CAD/CAM production process or possible further processing of the abutment can be obtained. The surface structures of the 3i BellaTek, Bego Semados, Zimmer Zfx, and Ankylos Compartis CAD/CAM zirconia abutments showed major shared features, indicating a similar production process. The different roughnesses could be attributable to the use of different diamond grits. The Astra Atlantis and the Nobel Procera abutment are manufactured according to a similar method but other processing instruments apparently were used. In the case of the CAD/CAM zirconia abutment from Nobel Procera, it can be assumed that coarser diamond grit was used during production, which would explain the greater surface roughness compared with the other test abutments. A different processing tool must have been used for the Straumann Cares abutment because of the assessible surface structure. The Camlog Dedicam abutment has the most unusual surface morphology. Erosions are seen, which suggest deliberate secondary processing. Grit blasting of the basal aspect of the CAD/CAM zirconia coping was possibly carried out prior to luting the coping to the titanium base in the laboratory. Since computer-aided construction and manufacture of custom implant abutments obviously involves different manufacturing and processing variations in specific systems, it appears reasonable to introduce a more precise definition that describes and differentiates the respective production process. Kapos and Evans have proposed the term "Complete CAD/CAM Product" for this, meaning that no or only minor manual interventions have been performed.[28]

Competing Interest

PG, WK and CF state that there are no conflicts of interest.

Authors' Contributions

PG, WK and CF contributed to the design of the study. PG and WK contributed to study selection and data extraction. All authors read, revised, and approved the final manuscript.

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Figure Legends

Fig. 1: Overview of the one- and two-piece CAD/CAM zirconia test abutments

Fig. 2: Prefabricated control abutments

Figs. 3a & b: CAD abutment construction in position 21 generated from a standardized wax-up of the respective abutment made of try-in resin. Labial and occlusal view in Abutment-Designer^{TM} Degudent/ 3 Shape.

Figs. 4a & b: Milled CAD/CAM zirconia abutment in position 21 on master model, labial and occlusal views

Fig. 5: Measurement points on the abutment

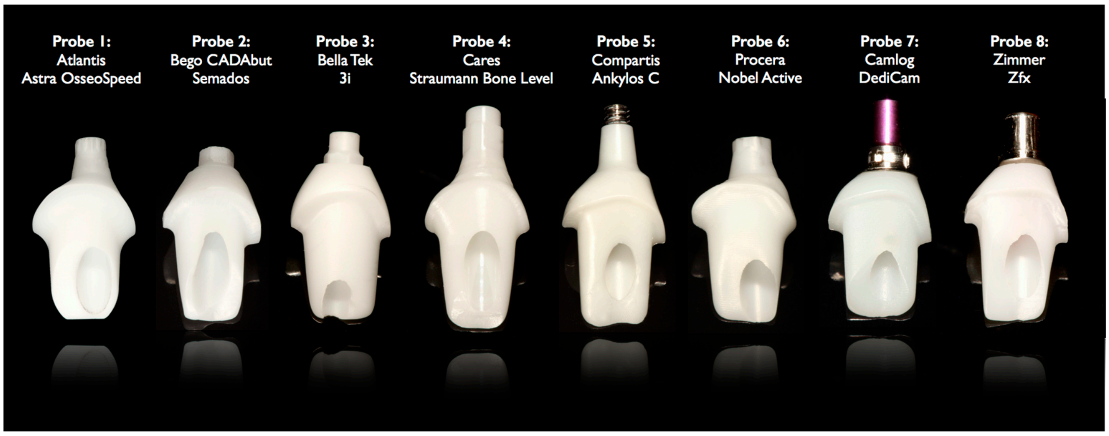
Fig. 6: Measurement segments for determining the R values (Ra, Rt): vertical red line.

Fig. 7: True-color display of all eight individual CAD/CAM ZrO_2 abutments from the labial side

Fig. 8: True-color display of all eight individual CAD/CAM ZrO_2 abutments from the palatal side

Fig. 9: False-color images of all eight individual CAD/CAM ZrO_2 abutments from the labial side

Fig. 10: False-color images of all eight individual CAD/CAM ZrO_2 abutments from the palatal side



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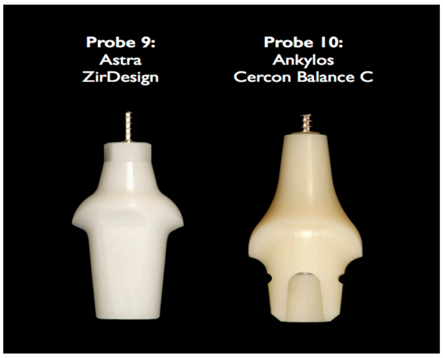

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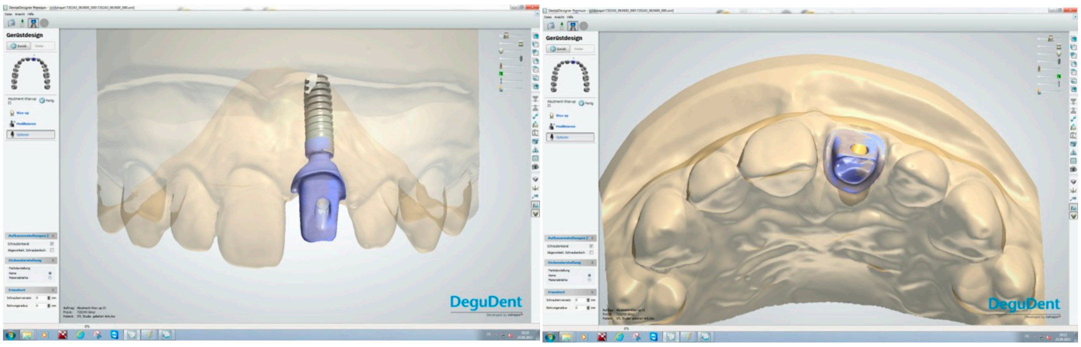

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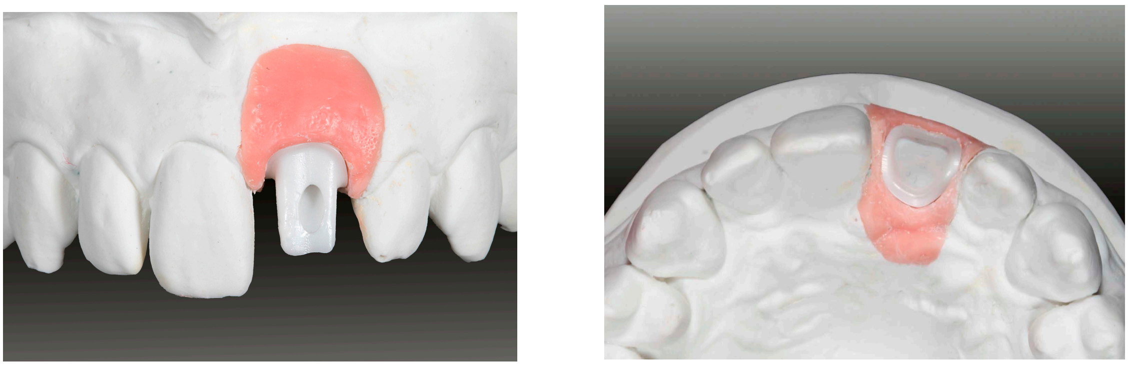

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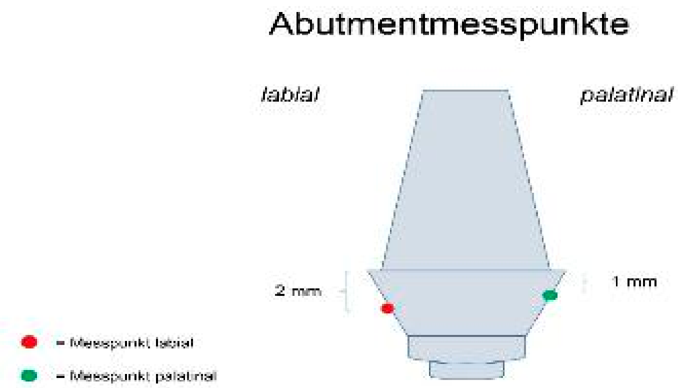

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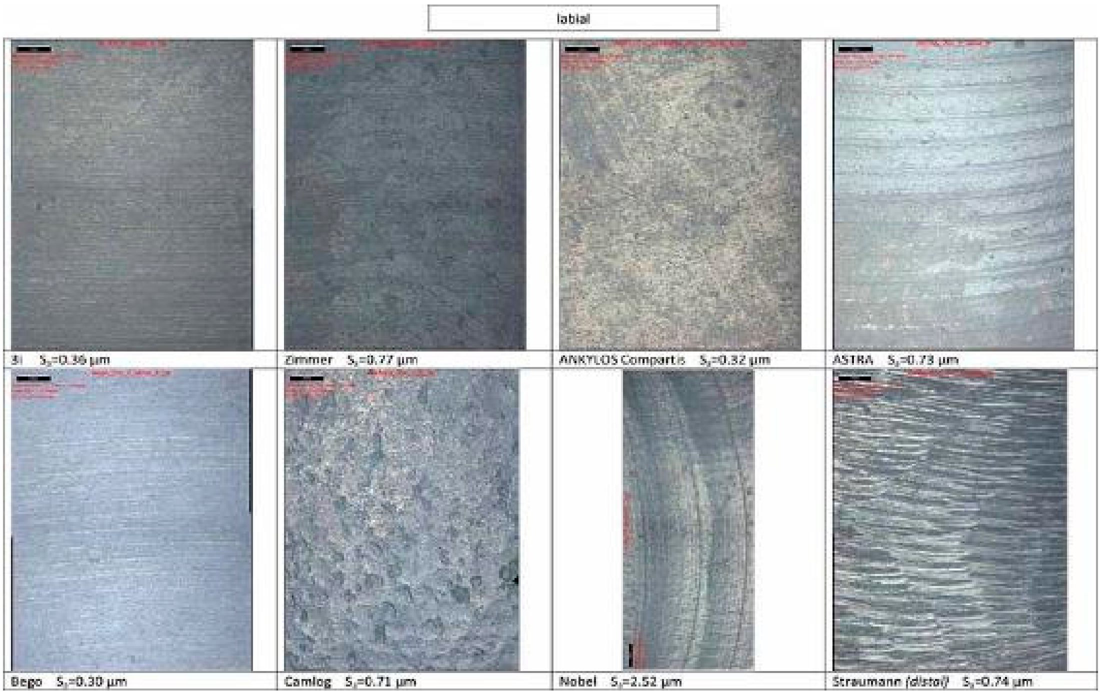

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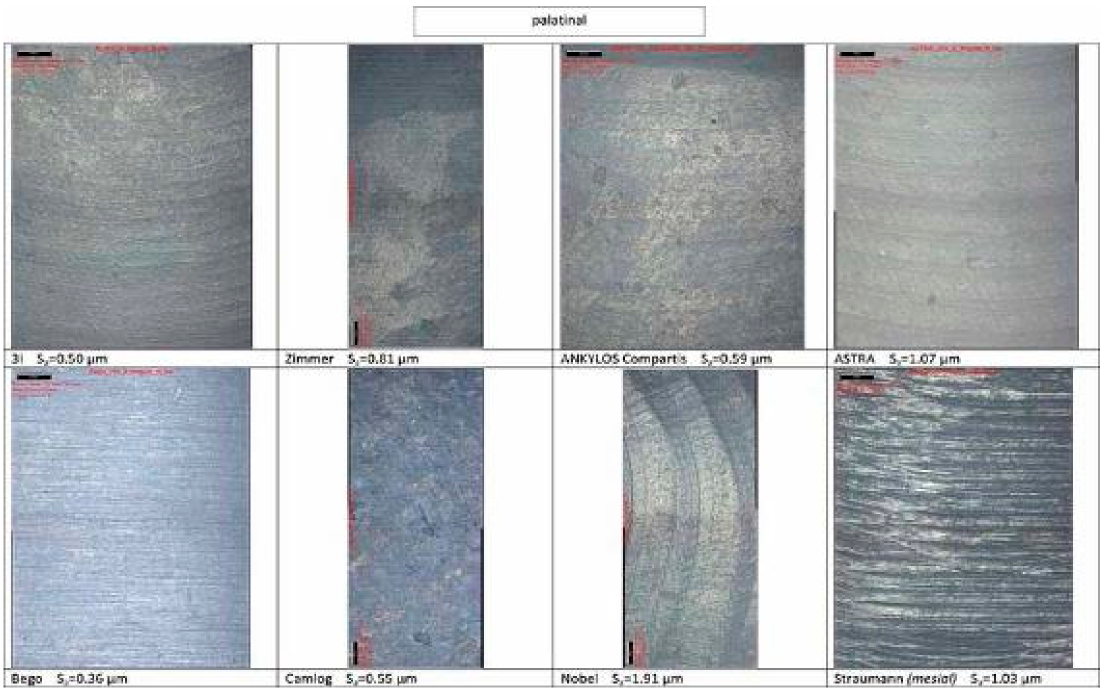

Fig. 8: True-color display of all eight individual CAD/CAM ZrO_2 abutments from the palatal side

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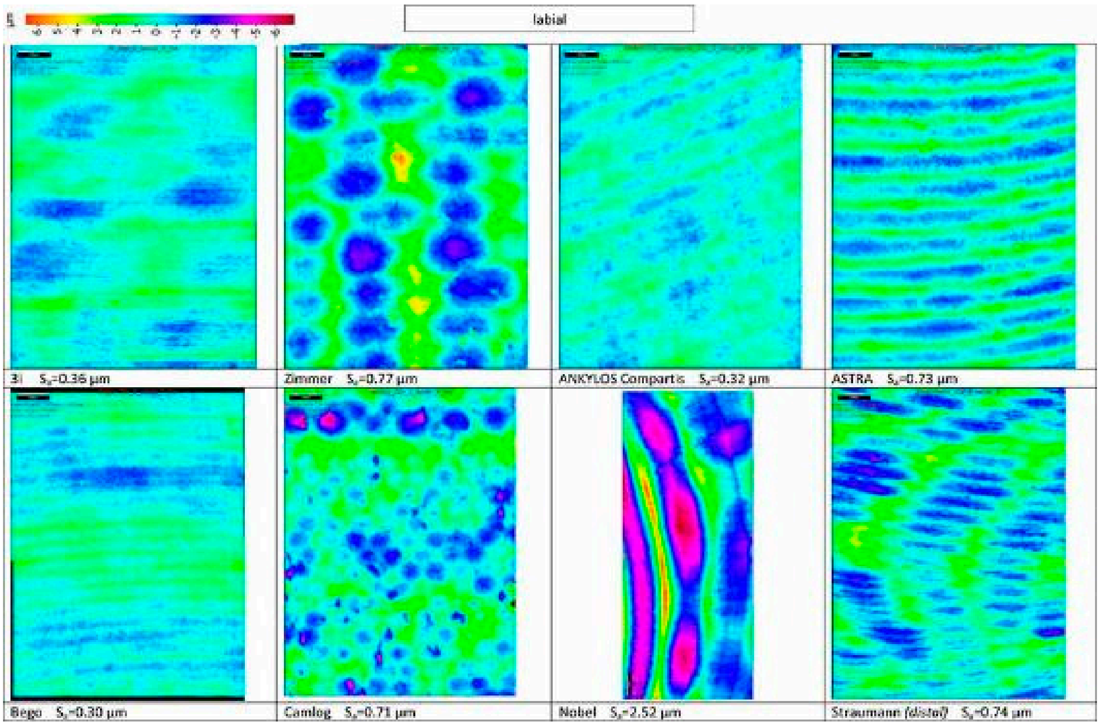


Fig. 9: False-color images of all eight individual CAD/CAM ZrO_2 abutments from the labial side

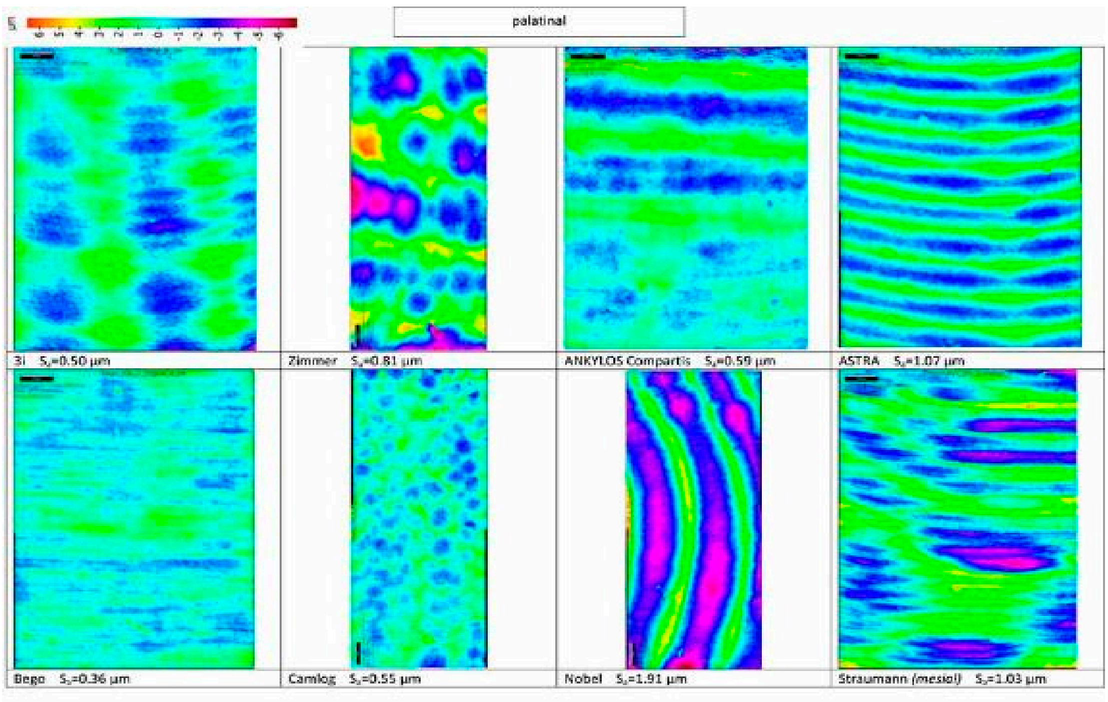
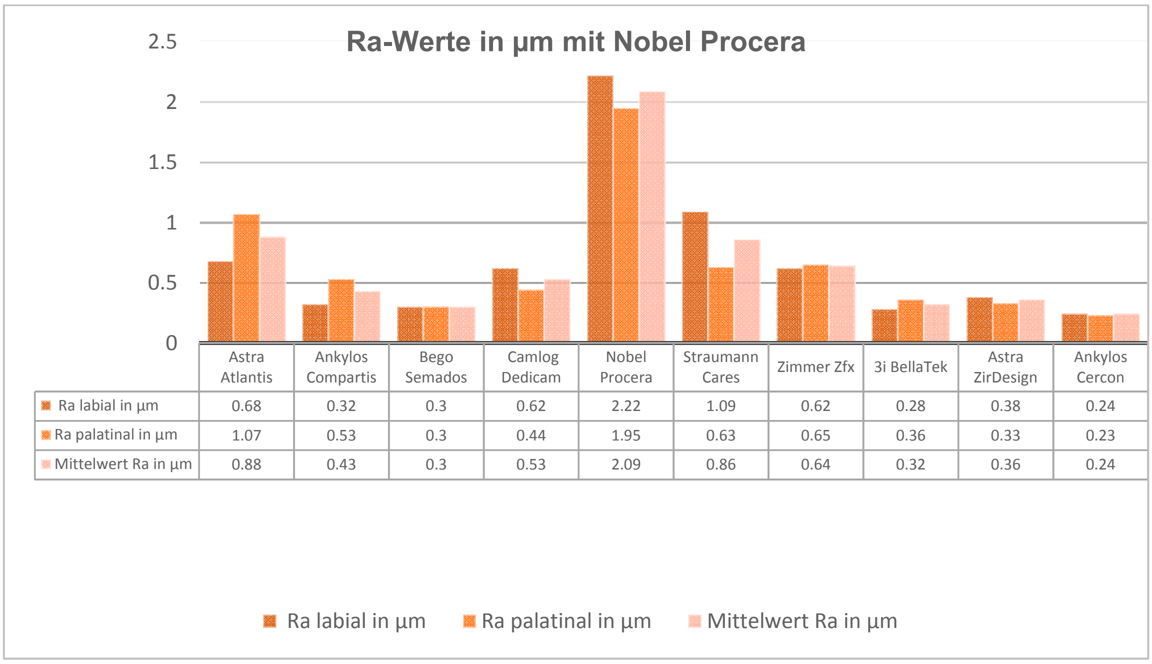


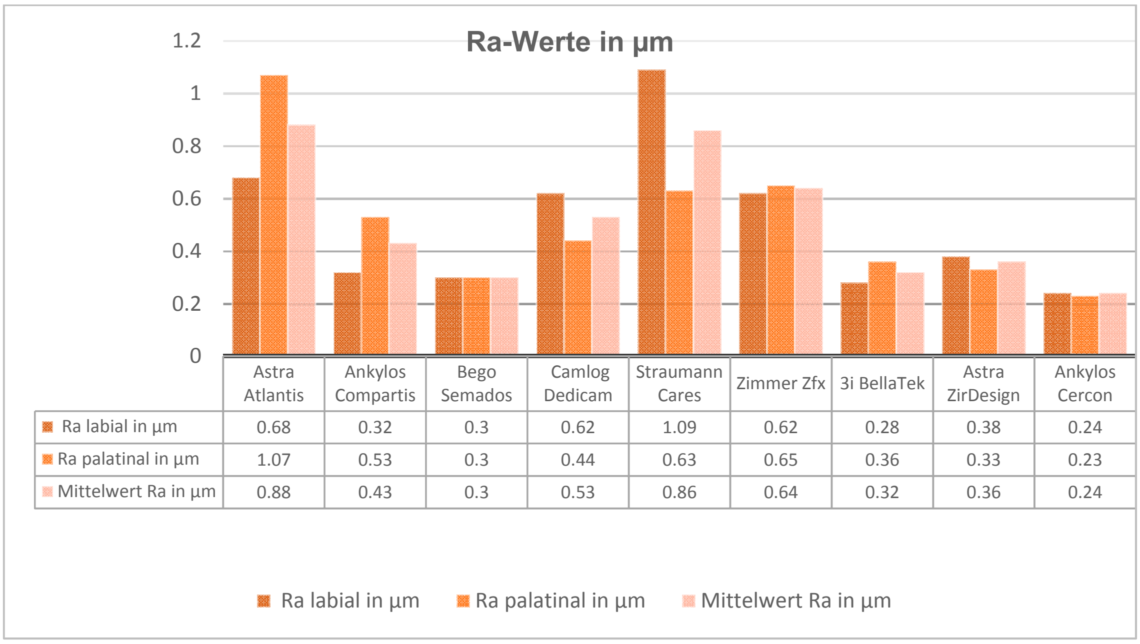
Fig. 10: False-color images of all eight individual CAD/CAM ZrO_2 abutments from the palatal side



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Nobel Procera	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Ra labial in µm	0.68	0.32	0.3	0.62	2.22	1.09	0.62	0.28	0.38	0.24
Ra palatinal in µm	1.07	0.53	0.3	0.44	1.95	0.63	0.65	0.36	0.33	0.23
Mittelwert Ra in µm	0.88	0.43	0.3	0.53	2.09	0.86	0.64	0.32	0.36	0.24

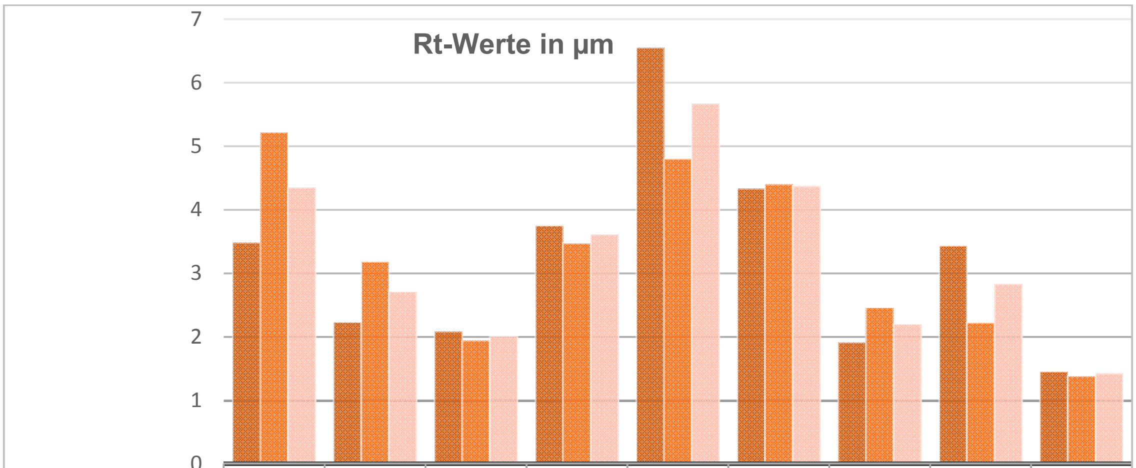
Table 1: Ra values with Nobel Procera abutment

Because of the much greater roughness of the Nobel Procera abutments (two to nine times greater), for greater clarity it was not included in the following graph of the individual results.



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Ra labial in µm	0.68	0.32	0.3	0.62	1.09	0.62	0.28	0.38	0.24
Ra palatinal in µm	1.07	0.53	0.3	0.44	0.63	0.65	0.36	0.33	0.23
Mittelwert Ra in µm	0.88	0.43	0.3	0.53	0.86	0.64	0.32	0.36	0.24

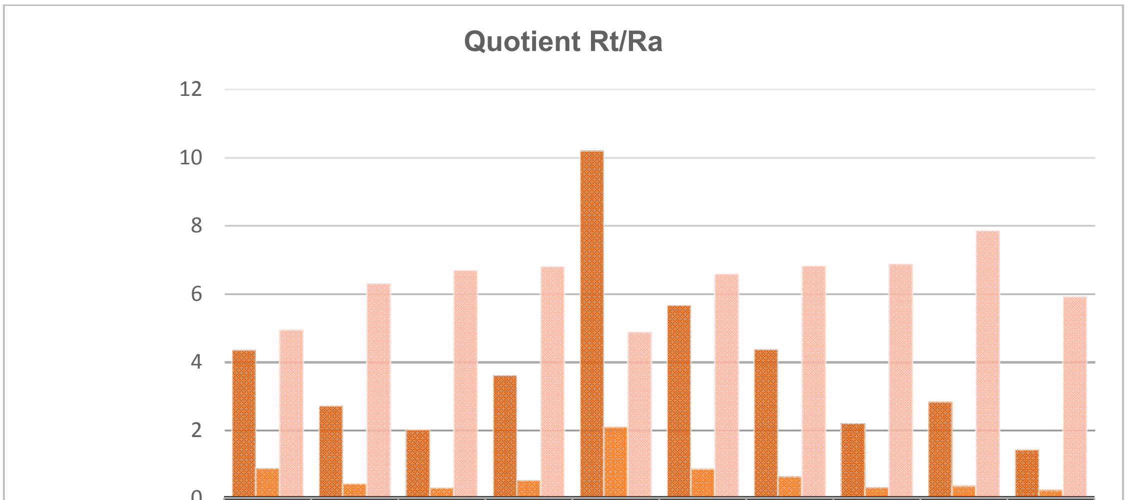
Table 2: Ra values without Nobel Procera abutment



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Rt labial in µm	3.48	2.23	2.08	3.75	6.55	4.33	1.91	3.43	1.45
Rt palatinal in µm	5.22	3.18	1.94	3.47	4.8	4.4	2.46	2.22	1.38
Mittelwert Rt in µm	4.35	2.71	2.01	3.61	5.67	4.37	2.2	2.83	1.42

Rt labial in µm   Rt palatinal in µm   Mittelwert Rt in µm

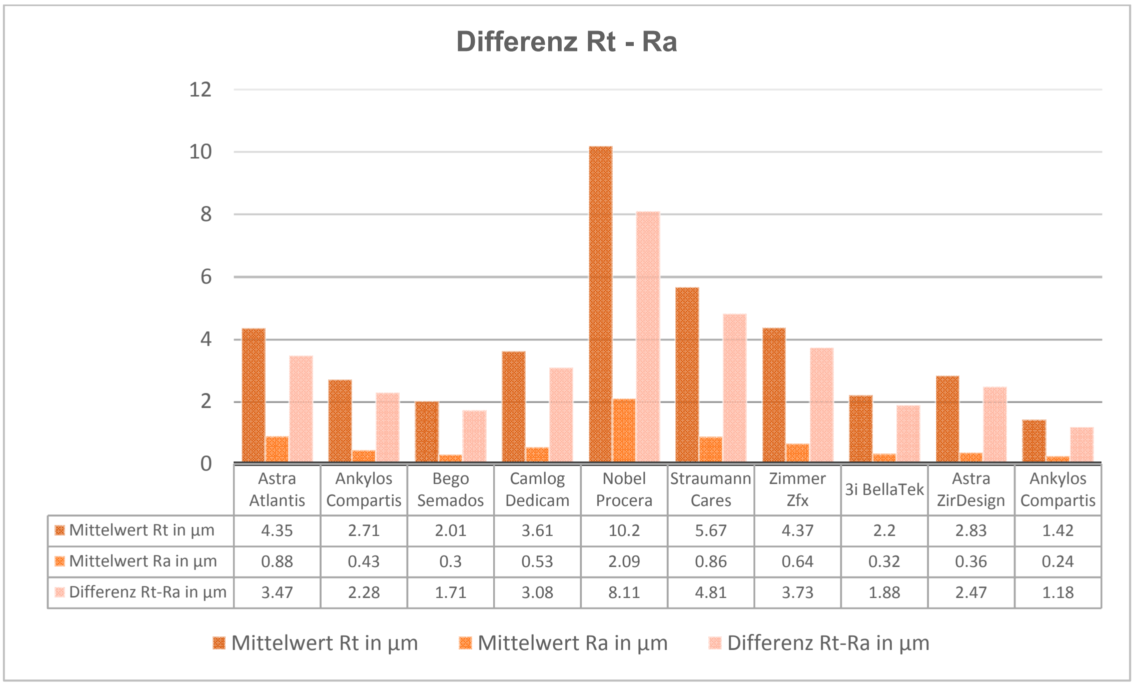
Table 3: Rt values without Nobel Procera abutment



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Nobel Procera	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Mittelwert Rt in µm	4.35	2.71	2.01	3.61	10.2	5.67	4.37	2.2	2.83	1.42
Mittelwert Ra in µm	0.88	0.43	0.3	0.53	2.09	0.86	0.64	0.32	0.36	0.24
Quotient Rt/Ra	4.94	6.3	6.7	6.81	4.88	6.59	6.83	6.88	7.86	5.92

Mittelwert Rt in µm   Mittelwert Ra in µm   Quotient Rt/Ra

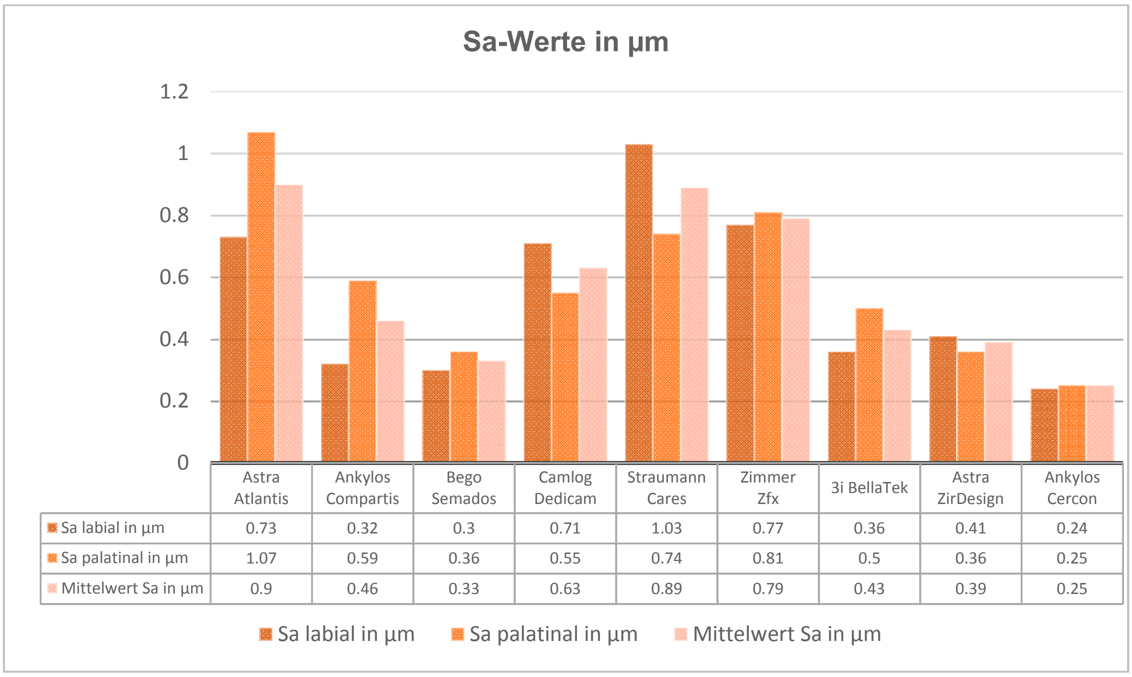
Table 4: Rt/Ra ratio with Nobel Procera abutment/ 2D measurements, Rt/Ra ratio, Rt – Ra difference



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Nobel Procera	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Compartis
Mittelwert Rt in µm	4.35	2.71	2.01	3.61	10.2	5.67	4.37	2.2	2.83	1.42
Mittelwert Ra in µm	0.88	0.43	0.3	0.53	2.09	0.86	0.64	0.32	0.36	0.24
Differenz Rt-Ra in µm	3.47	2.28	1.71	3.08	8.11	4.81	3.73	1.88	2.47	1.18

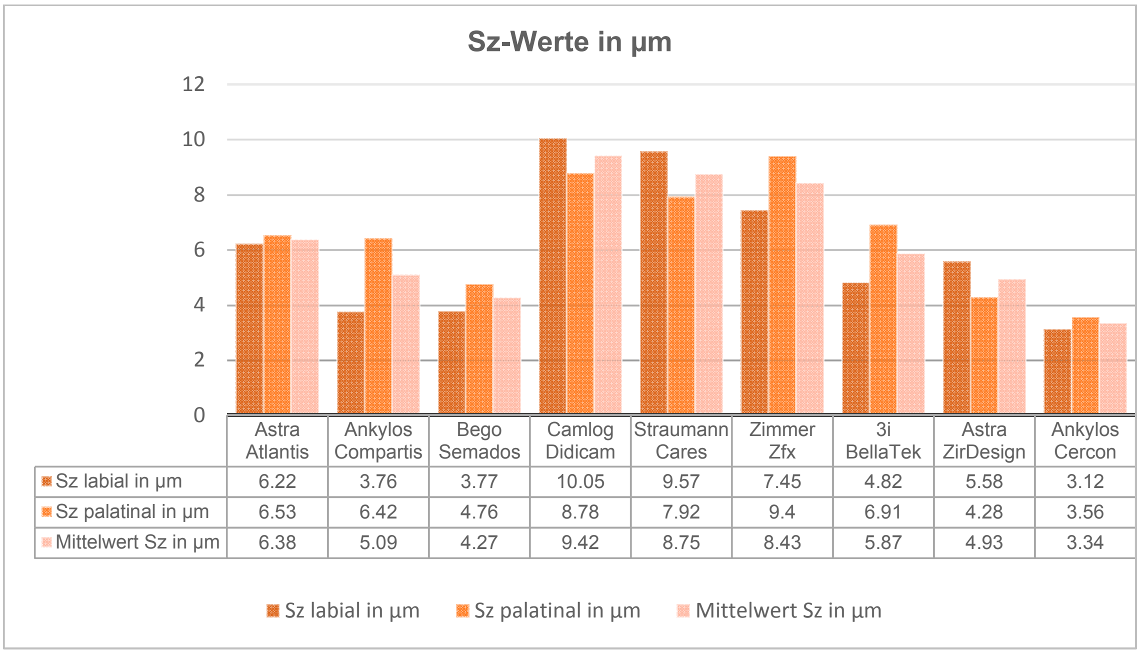
Table 5: Rt –Ra difference with Nobel Procera abutment

3D measurement data: Sa, Sz, Sdr



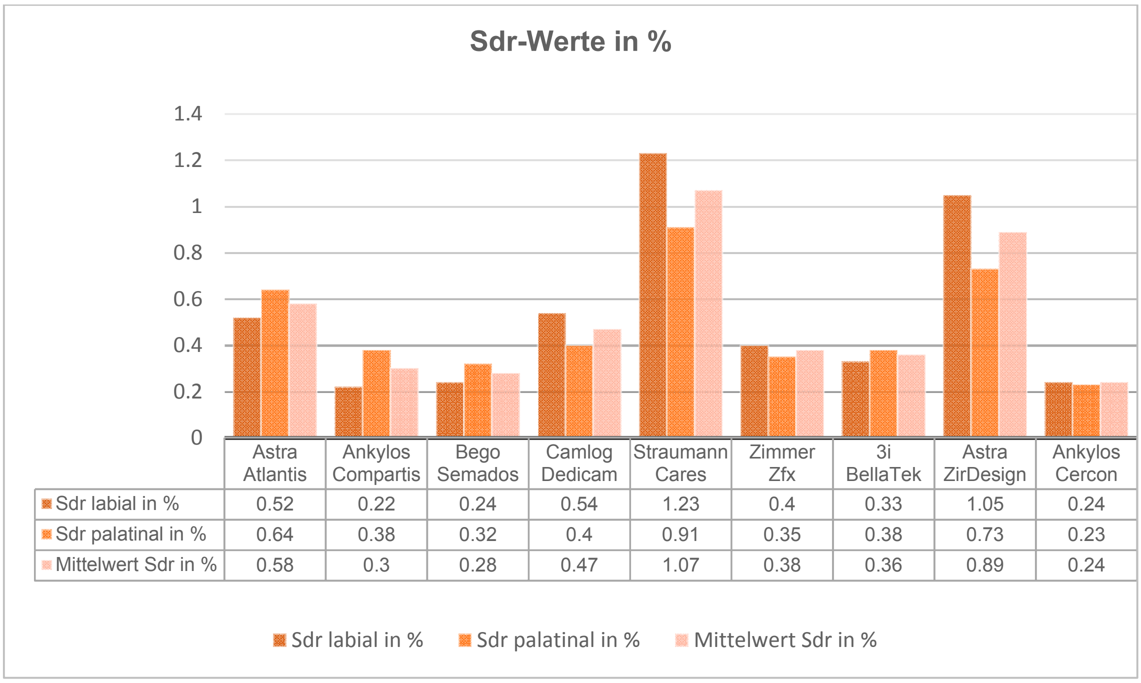
	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Sa labial in µm	0.73	0.32	0.3	0.71	1.03	0.77	0.36	0.41	0.24
Sa palatinal in µm	1.07	0.59	0.36	0.55	0.74	0.81	0.5	0.36	0.25
Mittelwert Sa in µm	0.9	0.46	0.33	0.63	0.89	0.79	0.43	0.39	0.25

Table 6: Sa values without Nobel Procera abutment



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Didicam	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Sz labial in µm	6.22	3.76	3.77	10.05	9.57	7.45	4.82	5.58	3.12
Sz palatinal in µm	6.53	6.42	4.76	8.78	7.92	9.4	6.91	4.28	3.56
Mittelwert Sz in µm	6.38	5.09	4.27	9.42	8.75	8.43	5.87	4.93	3.34

Table 7: Sz values without Nobel Procera abutment



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Sdr labial in %	0.52	0.22	0.24	0.54	1.23	0.4	0.33	1.05	0.24
Sdr palatinal in %	0.64	0.38	0.32	0.4	0.91	0.35	0.38	0.73	0.23
Mittelwert Sdr in %	0.58	0.3	0.28	0.47	1.07	0.38	0.36	0.89	0.24

Table 8: Sdr values in % without Nobel Procera abutment

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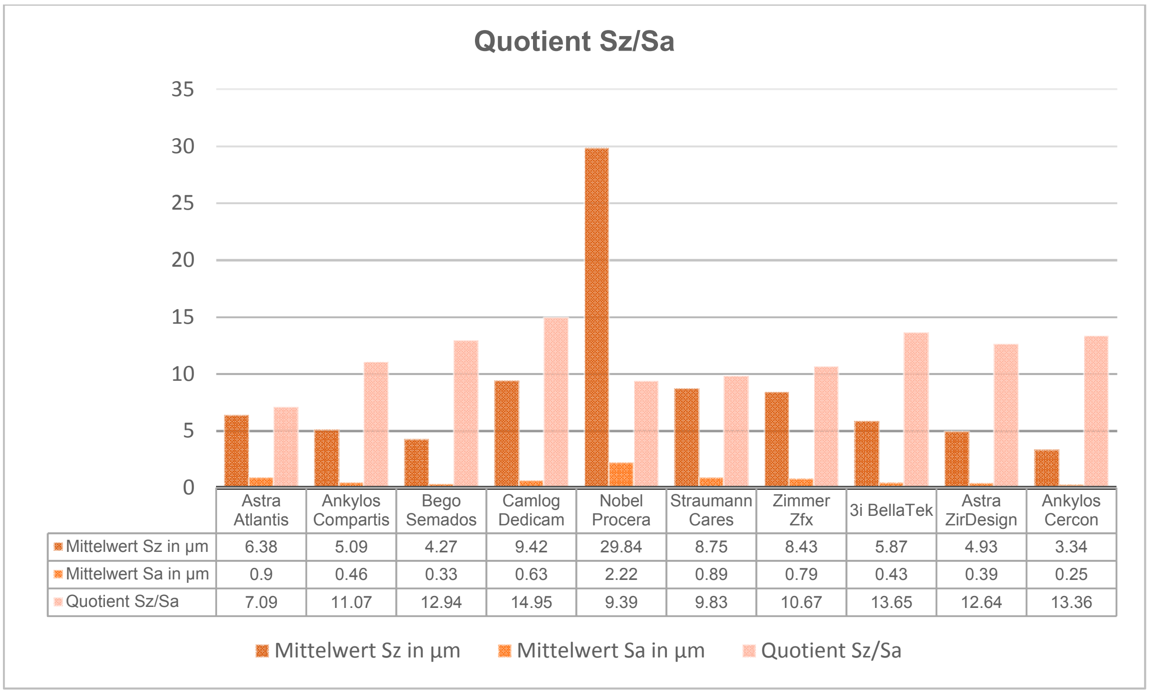
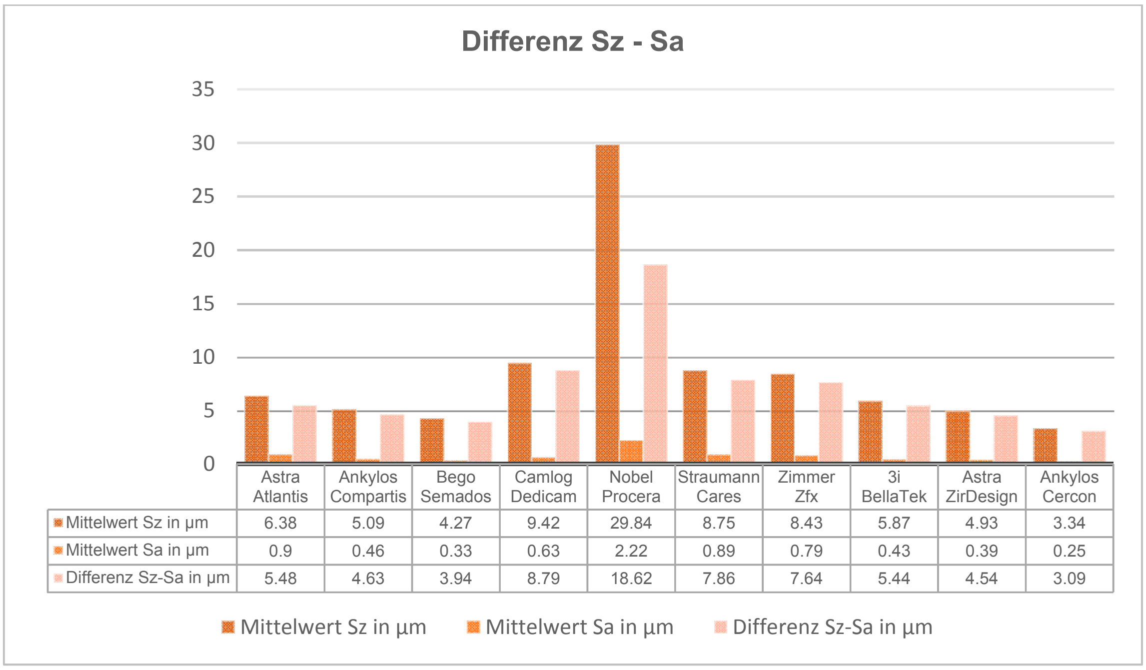
3D measurement data: Sz/Sa ratio, Sz – Sa difference



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Nobel Procera	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Mittelwert Sz in µm	6.38	5.09	4.27	9.42	29.84	8.75	8.43	5.87	4.93	3.34
Mittelwert Sa in µm	0.9	0.46	0.33	0.63	2.22	0.89	0.79	0.43	0.39	0.25
Quotient Sz/Sa	7.09	11.07	12.94	14.95	9.39	9.83	10.67	13.65	12.64	13.36

Table 9: Sz/Sa ratio with Nobel Procera abutment



	Astra Atlantis	Ankylos Compartis	Bego Semados	Camlog Dedicam	Nobel Procera	Straumann Cares	Zimmer Zfx	3i BellaTek	Astra ZirDesign	Ankylos Cercon
Mittelwert Sz in µm	6.38	5.09	4.27	9.42	29.84	8.75	8.43	5.87	4.93	3.34
Mittelwert Sa in µm	0.9	0.46	0.33	0.63	2.22	0.89	0.79	0.43	0.39	0.25
Differenz Sz-Sa in µm	5.48	4.63	3.94	8.79	18.62	7.86	7.64	5.44	4.54	3.09

Table 10: Sz –Sa difference with Nobel Procera abutment

	Ra mean in µm	Rt mean in µm	Sa mean in µm	Sz mean in µm	Sdr mean in %
Astra Atlantis	0.88	4.35	0.9	6.38	0.58
Ankylos Compartis	0.43	2.71	0.46	5.09	0.30
Bego Semados	0.3	2.01	0.33	4.27	0.28
Camlog Dedicam	0.53	3.61	0.63	9.42	0.47
Nobel Procera	2.09	10.2	2.22	20.84	1.56
Straumann Cares	0.86	5.67	0.89	8.75	1.07
Zimmer Zfx	0.64	4.37	0.79	8.43	0.38
3i BellaTek	0.32	2.2	0.43	5.87	0.36
Astra ZirDesign	0.36	2.83	0.39	4.93	0.89
Ankylos Cercon	0.24	1.42	0.25	3.34	0.24

Table 11: Table of the means of all 2D and 3D measurements.

Formula: mean (parameter) = (labial measurement + palatal measurement): 2

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	Sa value	Assessment parameter
Smooth surface	Sa < 0.2 μm	Insufficient connective tissue adherence (too smooth)
Moderately rough surface	Sa 0.21-0.4 μm	Tolerance range for optimal surface roughness
Rough surface	Sa >0.41 μm	Risk of plaque accumulation is greater than the advantage of stable connective tissue adherence

Table 12: Guide for assessing the surface roughness of ceramic abutments (SRCA). (Sz values of < 2 μm and Sdr values of < 0.25% are regarded as optimal)