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Marginal fit of CAD/CAM restorations on the basis of CBCT and their optical behavior.

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To my parents and sisters whose have always supported my dreams and ambitions.

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LIST OF ABBREVIATIONS

CAD/CAM - Computed Aided Design and Computed Aided Manufacturing

CNC - Computer Numerical Control

CBCT - Cone-Beam Computed Tomography

IOS - Intraoral Scanners

EOS - Extraoral Scanners

PhD - Doctor of Philosophy

3D - three-dimensional

DICOM - Digital Imaging and Communications in Medicine

STL - Standard Triangulation Language

µm - Micrometer

PMMA - Poly methyl methacrylate

n - sample size from each group

N - sample size from all groups

mA - Milliampere.

kV - Kilovolt

mGy·cm2 - Miligray/ centimeters squared

FOV - Field of view

nm - Nanometer

T% - Transmittance

Mm - Millimeter

VDO - Vertical Dimension of Occlusion

IDS - International Dental Show

LIST OF PUBLICATIONS

JOURNAL PUBLICATIONS

1. **Kauling AEC**, Keul C, Erdelt K, Kühnisch J, Güth JF. Can lithium disilicate ceramic crowns be fabricated on the basis of CBCT data? Clin Oral Investig. 2019 doi: 10.1007/s00784-019-02802-6. [Epub ahead of print]

2. **Kauling AEC**, Liebermann A, Güth JF. 15 Years of Self-Adhesive Resin-Based Cements. Eur J Prosthodont Restor Dent., 2018, Special Issue, p.7-16.

3. Liebermann A, Rafael CF, **Kauling AEC**, Edelhoff D, Ueda K, Seiffert A, Volpato CAM, Güth JF. Transmittance of visible and blue light through zirconia. Dent Mater J, 2018, v.37, p.812-817.

4. Güth JF, **Kauling AEC**, Schweiger J, Kühnisch J, Stimmelmayr M. Virtual simulation of periodontal surgery including presurgical CAD/CAM fabrication of tooth-colored removable splints on the basis of CBCT data: a case report. Int J Periodontics Restorative Dent, 2017, v.37, e310–e320.

5. Rafael CF, Güth JF, **Kauling AEC**, Cesar PF, Volpato CAM, Liebermann A. Impact of background on color, transmittance, and fluorescence of leucite based ceramics. Dent Mater J, 2017, v.36, p.394-401.

6. Güth JF, **Kauling AEC**, Ueda K, Florian B, Stimmelmayr M. Transmission of light in the visible spectrum (400-700 nm) and blue spectrum (360-540 nm) through CAD/CAM polymers. Clin Oral Investig. 2016, v.20, p.2501-2506.

7. Melo EV, **Kauling AEC**, Freitas SFT, Cardoso AC, Ferreira CF. The Ability of Dental Specialists to Distinguish Lateral Incisor Metal-Free from Porcelain-Fused-to-Metal Implant Supported Crowns. Eur J Prosthodont Restor Dent., 2014, v.22, p.153-158.

PRESENTATIONS IN CONGRESSES

1. **Kauling AEC**, Erdelt K, Güth JF.
   Deutscher Zahnärztetag, 2018.
   Können Lithiumdisilikat-Kronen auf der Basis von DVT Daten hergestellt werden?

2. **Kauling AEC,** Liebermann A, Rafael CF, Edelhoff D, Güth, JF.
   IADR (International Association for Dental Research) General Session, 2017.
   Transmittance of Visible and Blue light through CAD/CAM Materials

3. Schweiger J, **Kauling AEC,** Erdelt K, Güth, JF.
   Academy of Dental Materials - Annual Meeting, 2017.
   In vitro evaluation of mechanical quality of casted/laser-sintered clasps for removable dentures

4. **Kauling AEC,** Melo EV, Souza Junior JM, Shuldt Filho G, Dalago HR, Cardoso AC, Freitas, SFT.
   IADR (International Association for Dental Research) Latin Am. Reg. Meeting, 2012.
   Perception on metal free/ PMF Implant supported crowns: Blinded controlled study.

5. **Kauling AEC,** Volpato, CAM, Teixeira, KN.
   28 SBPqO - Annual Meeting, 2012.
   Avaliação radiográfica da qualidade endodôntica e protética de 200 núcleos metálicos fundidos: estudo retrospectivo.

GENERAL INTRODUCTION

INTRODUCTION

The conventional process of fabrication of dental restorations involves many different types of materials, manual work steps, as well as many clinical and laboratory stages that might limit the accuracy and predictability of the resulting restorations.[1,2,3,4,5] To enhance quality and reproducibility, different digital technologies were developed and introduced to the dental market aiming to improve quality management, and predictability, as well as providing access to new materials. [6]

As a result, CAD/CAM (Computed Aided Design and Computed Aided Manufacturing) systems have been actively applied worldwide since the 1980s in dentistry, while commercial dental CAD/CAM systems have been introduced for specific fields, such as all-ceramic restorations in the past two decades.[7]

The CAD/CAM workflow in dentistry is based on three parts: a data acquisition unit for the computer aided impression, a software for the design of the restoration (CAD) and a computer assisted manufacturing device (CAM) to fabricate dental restorations. The restorations are designed on the basis of a virtual working cast of the dental situation and then the milling/grinding parameters are computed. Using computerized fabrication devices, the restorations are milled or grinded (CNC - Computer Numerical Control) from a solid block of restorative material or they are manufactured by additional manufacturing devices.[8,9]

As a logical consequence, in addition to technological developments, a strong trend towards monolithic restorations can also be observed in the dental market. This means that dentists and dental technicians need to acquire knowledge regarding technology and materials. The optical behavior of a material plays an important role when it is used to fabricate a monolithic restoration since almost no manual corrections of the color and esthetic appearance are possible.

The present work focuses on the technology according to the digitalization method, as well as the materials and their clinical applications.

OBJECTIVES:

The main objectives of the present thesis were:

- Project 1: To analyze the digitalization process using cone-beam computed tomography as a data acquisition unit by evaluating the marginal fit of the resulting CAD/CAM lithium disilicate ceramic crowns obtained through indirect digitalization (1 Extra-Oral scanner and 2 cone-beam computed tomography) and direct digitalization (1 Intra-Oral scanner) and to verify if the superiority of the new technologies interferes with the quality of the final data.

- Project 2: To examine the optical behavior of CAD/CAM materials for monolithic use by evaluating the transmittance of light in the blue and visible spectrum through of CAD/CAM polymers using a feldspathic glass-ceramic as control group.

- Project 3: Evaluate the digital integrated treatment-planning according to the interaction of different digital technologies with monolithic materials, achieved by experienced dental teams and the predictability of clinical outcomes.

Digitalization process using CBCT

Generally, data acquisition can be performed in 2 different ways: direct digitalization by an *IOS-intraoral scanner* – that captures the clinical situation directly in the patient´s mouth or by indirect digitalization using an *EOS-extraoral scanner* to scan a stone model generated from a conventional impression. Instead of an EOS, a *CBCT - cone-beam computed tomography* image might also be used to digitize a conventional impression, which was the technique evaluated in the current PhD-thesis.

The implementation of CBCT in dentistry enabled the possibility to perform a digital 3D approach for data acquisition and image reconstruction in dental radiology. However, the use of CBCT data by other digital devices is limited, taking into consideration that CBCTs and CAD/CAM systems operate in different data formats. CBCT data is formatted in DICOM (digital imaging and communications in medicine) while CAD/CAM data is formatted in STL (standard triangulation language). In this regard, software to convert DICOM data to STL data was developed. Besides data conversion, these software (e.g. InVesalius) also enable the soft tissue (the clinically covered tooth structures) to be filtered out and the bone to be uncovered. Thereby, the hard tissues can be exposed, a situation that allows the filtered STL data to be used by CAD/CAM systems to manufacture splints, surgery guides or models.[10,11] The accuracy of the STL data obtained from CBCT depends on the quality of the DICOM data and the quality of the conversion software.[12,13] Güth et al 2017 reported differences between STL-files filtered from CBCT and datasets of a scanned situation model within a range of 100µm using a best-fit-algorithm. For fixed prosthetic restorations, a marginal fit of 120µm or less is desirable for full crowns from a clinical standpoint.[14,15,16,17] Regarding this, Śeker et al 2016 developed a study evaluating a CBCT image as a data acquisition unit. In the present study, a prepared single tooth was directly digitized by CBCT in 3 different voxel sizes. The resulting data served as basis to manufacture PMMA copings, whose marginal fit accuracy was verified by the replica technique.[18] The outcomes revealed that the crowns obtained with a voxel size of 125µm showed marginal fit within a clinically acceptable range of 103µm. However, the precision of the data obtained by scanners and digital devices such as CBCTs has to be compared to the conventional workflow outcomes to evaluate their reliability and competitiveness.[19,20] In addition, no control group was used and the CBCT scan was taken directly from a prepared tooth, not from the impression. Applying this technique to patients would be clinically questionable due to radiation exposure.

Against this background, studies showed promising accurate results for the use of CBCT data[10,11,12], however, the clinically decisive fit of final restorations has not yet been evaluated. Therefore, the first publication in the present thesis focused on the marginal fit of single crowns out of lithium disilicate fabricated on the basis of a CBCT scan of conventional impressions using two different CBCT scanners (CBCT1 and CBCT2) and to compare it to known ways of digitalization using an indirect approach (EOS of conventional impressions models) and a direct approach using an intraoral scanner (IOS). Kauling 2019 is the only available study that compared the marginal fit of grinded ceramic crowns based on the data of two different generations of CBCTs. The present study´s methodology aimed to confirm the accuracy of the converted STL data generated by CBCTs and to verify if the enhancement of the new technologies interferes with the quality of the final data. To this regard, a metal model with a molar chamfer preparation was digitized (n = 12 per group) in four distinct manners: IOS direct digitalization using an intra-oral scanner (CS3600), cone-beam computed tomography scan (CBCT 1) indirect digitalization of the impression (CBCT-CS9300), CBCT 2 indirect digitalization of the impression (CBCT-CS8100), and extra-oral scanner (EOS) indirect digitalization of the gypsum-cast (CeramillMap400). To evaluate the accuracy of the digitalization systems, STL datasets from all groups (N=48; n=12) were exported from the digitalization units and imported into the inspection software. Next, the dataset (N=48) was imported to a CAD software where one reference crown was designed and matched with all datasets in order to standardize the outline of all final crowns. The 48 crowns were grinded out of lithium disilicate ceramic blocks, and their marginal fit was evaluated through the replica technique.

Regarding the CBCT setting parameters that determinate the quality of the image (mA, kV, time, mGy·cm2, FOV, voxel size), the voxel size establishes the image resolution. CBCT CS9300 (CBCT 1) shows a maximal resolution of 90µm, but the setting parameters to scan impressions are fixed and the voxel is 200µm. In the case of CBCT CS8100 (CBCT 2), the maximal resolution is 75µm, but the impression setting parameters show two configurations of voxel size: high quality (90µm) and standard quality (150µm). The high-quality resolution was tested with the goal to obtain more accurate data, but the STL scan data showed many artifacts in the images that did not correspond to the real object. The authors believe that the artifacts generated by the more precise voxel size occurred because of the noise. The smaller the voxel size is, the higher is the spatial resolution and the noise.[21] The less precise configuration of 150µm was then used in order to eliminate the artifacts (by reducing the noise) and to obtain the best resolution possible for the CBCT 2.

Thus, the final results of marginal fit showed differences within a range of 96µm, 68µm, 56µm and 51µm for the CBCT 1, CBCT 2, EOS and IOS, respectively. These outcomes confirm that the use of CBCT data obtained from digital impressions might be indicated to serve as a basis to manufacture lithium disilicate crowns, though crowns from the IOS and EOS showed better marginal fit. Although the results from the CBCT 2 showed better accuracy than the CBCT 1, they were not statistically significant. Meanwhile, the final outcomes suggest that the calibration of impressions setting parameters combined with further data processing improvements might enhance the accuracy of the converted STL data obtained from CBCTs.

The use of CBCTs as data acquisition units is a possibility exclusively for indirect digitalization. The high radiation doses produced during a CBCT scan, contraindicate the use of CBCTs as a way of direct digitalization. It is important to highlight that the studies including patient initial data mentioned in the present work used CBCT data previously acquired as a basis of precise diagnoses and treatment planning for complex rehabilitations. Still, also for these cases, the radiation exposure has to be balanced with the clinical benefit. Nevertheless, a few *in vitro* studies were carried out aiming to minimize the amount of radiation exposure during a CBCT scan,[22,23] however, for now, the major recommendation is to use CBCT to scan only impressions and gypsum casts.[9]

Optical behavior of CAD/CAM materials for monolithic use

Monolithic CAD/CAM restorative materials are designed to reduce the costs of fabrication of restorations, yet, maintaining its mechanical properties. CAD/CAM technology enables the manufacturing of highly accurate monolithic restorations with a more homogenous composition and fewer imperfection voids compared to the traditional conventional workflows.[7,24] The use of monolithic materials sometimes even eliminates the need of plaster casts for the final firing steps (required to fabricate conventional ceramic-based restorations), it reduces time consumption and costs of the fabrication process; besides enabling a complete digital workflow with more standardized, reliable and predictable results.

The application of monolithic restorations in dentistry is widely indicated, since the range of materials varies from PMMA over composites, silicate ceramics up to zirconia. Within this field, monolithic blocks from CAD/CAM- fabricated polymer materials have also been developed as an option to analogically polymerized material. These materials are polymerized under monitored and standardized industrial parameters (temperature, pressure), resulting in a high conversion rate that leads to fewer residual monomers, and therefore, higher biocompatibility. Therefore, CAD/CAM-manufactured interim restorations from automatized resin blocks show higher mechanical stability compared to analogically manufactured ones.[25,26,27]

With monolithic restorations, the outer form, surface structure, translucency and color of the luting resin determinate the esthetic appearance of the restoration.[10] In the case of CAD/CAM polymers, adhesive luting seems to be necessary due to its high elasticity to achieve clinical success. For esthetics and also for luting procedures, the material´s translucency plays a key role. To select the material (for color matching) and to control the esthetics of dental restorations, the translucency in the visible light spectrum is a crucial factor.[28] Translucency is also fundamental in deciding which form of luting procedure, dual-cure or light-cure, should be used. However, for luting procedures the transmittance of the material in the blue light spectrum (360 to 540 nm) is decisive.[29] Therefore, the second publication in the present thesis aimed to verify the permeability of CAD/CAM polymers for light in the visible and the blue spectrum, 400 to 700 nm and 360 to 540 nm respectively, using feldspathic glass ceramic as a control group. For the present study, 11 distincts CAD/CAM polymers (Telio CAD, Cercon base PMMA, CAD Temp, Artbloc Temp, Ambarino High-Class, Polycon ae, New Outline CAD, Zenotec PMMA, Paradigm MZ 100, QUATTRO DISK Eco PMMA and Lava Ultimate) and 1 feldspathic glass ceramic (Vita Mark II) material were evaluated. Disk-shaped test specimens (thickness of 1 ± 0.03 mm) from each material with comparable colors (A3) were prepared (n = 40 each material, N = 480 in total). The light transmittance at blue spectrum and visible spectrum, wavelengths (λ) from 360–540 nm and 400-700 nm, were measured using a spectrophotometer, calibrated with intervals of 2 nm. The samples were placed in front of an integrating sphere of the spectrophotometer to measure the overall light transmittance. To evaluate the light transmittance (T%), the overall light transmittance value of each material was divided by the overall light transmittance value with no sample in the spectrophotometer, (baseline) to receive light transmittance in %. This baseline value was obtained from 40 measurements of light transmittance with no sample in the spectrophotometer. The results of these measurements reveled that all groups, including control group, showed significant differences between the transmittance of blue and visible light. The glass ceramic group showed the highest transmittance for blue spectrum (41.44 %). For the CAD/CAM polymers, transmittance varies from 13.96 to 40.52 % within the blue spectrum, and all materials showed significant different overall transmittance, except for the Polycon ae and Artbloc Temp ($p = 0.99$), which have the same composition but are fabricated from different companies, and for Paradigm MZ 100 and TelioCAD ($p = 0.47$). In clinical terms, these results mean that if the indicated curing time of a luting material was calculated for 100% of blue light transmittance, by using the glass ceramic evaluated in this study (41.44 % of blue light transmittance) the curing time has to be 2.4 times higher. However, if only 13.96 % of blue light is transmitted (Polycon ae), the curing time has to be around 7 times longer. This limits light curing luting resins to be used in cases of extensive rehabilitations due to the time required to perform the curing procedure for these materials. In these cases, the use of dual-cured resins would be an alternative as it requires less time and also due to the polymerization achieves better results than with light-cured luting composite in extreme conditions. However, the use of additional light curing to dual-curing resins, leads to enhance physicochemical properties compared to a self-curing resin, i.e., better micromechanical properties leads to increase biocompatibility and the degree of conversion.[30]

Another variable that influences the amount of light that passes through the material is the thickness of restorations. Previous studies that evaluated the transmittance of glass ceramic and zirconia, glass ceramic showed higher transmittance than zirconia. However, with a thickness of 2.5mm or more glass ceramic and zirconia showed almost no transmittance differences. [31,32]

Comparing the light transmittance of visible spectrum with blue spectrum, significant differences could be observed. In general, the materials showed higher transmittance for visible than for the blue spectrum. This suggests that practitioners should not make conclusions from the blue spectrum transmittance of a material according to its visible spectrum transmittance. This influences the luting procedure´s considerations. The use of CAD/CAM materials requires good knowledge and information about the optical properties of the material and the bonding procedures to be used. [29]

Digital Integrated Treatment-Planning

The connection of different digital technologies and materials can enhance the predictability of clinical outcomes in complex rehabilitations, whereas the integration of CBCT data, scanners data, 3D Face Scan, digital articulator with CAD/CAM monolithic materials leads to a more precise and safer treatment planning and, as a consequence, more accurate treatment outcomes for the patient. [10]

Monolithic materials such as CAD/CAM polymers show a lot of advantages to be used in digital integrated treatment planning due to its superior properties that enable the use over longer clinical periods, thus facilitating treatment planning, mainly in complex cases. The combination of digital technology and CAD/CAM polymers offers a variety of new treatment options, such as the fabrication of removable tooth-colored splints to be placed directly after periodontal surgery. These splints fulfill multiple functions, being used as a guide for soft tissue incisions and bone remodeling, enabling optimal dental hygiene during the healing period, or a prolonged pretreatment stage to improve the quality and predictability of the end results in complex cases in addition to rehabilitations with VDO - vertical dimension of occlusion decreased and/or severe loss of tooth structure and by providing an efficient and minimally invasive intermediary treatment period.[33,34,35]

Digital technologies offer the possibility of early patient involvement in the planning procedure and provide a great communication tool. Clinicians and dental technicians should work together as a well-synchronized team, making the best use of digital technology resources to provide more accurate and predictable treatments for the patient. The development of interfaces between already existing digital technologies enables innovative treatment options that would not be possible with analog methods alone. Despite the rapid development of digital dentistry, classic conventional procedures are still the standard for correct treatment in multidisciplinary full-arch rehabilitations. However, the conventional procedures complemented by innovative CAD/CAM materials, especially CAD/CAM polymers, and digital tools enable dental practitioners to achieve more predictable and accurate treatment outcomes. [10]

The current digital and conventional scenario suggests that the more digital systems enhance technologically, the smaller the differences and limitations in relation to conventional workflows. Some of the latest generations of CBCTs presented in the last IDS (International Dental Show- 2019), provided already existing digital devices such as 3D Face Scan attached to their software. Another novelty is the possibility to connect digital devices such as intraoral scanners to the CBCT in some machines. The authors truly believe that the use of these digital technologies combined with the use of CAD/CAM monolithic materials can enhance the predictability of clinical outcomes, especially in complex cases and situations in which the conventional workflow is limited. [10]

SUMMARY:

The use of CBCT data obtained from dental impressions might be indicated to serve as a basis to manufacture lithium disilicate crowns with a marginal fit in the range of clinical acceptance. Furthermore, the results of the present study suggest that new technologies associated with software improvements might enhance the quality of the data obtained from CBCT. Monolithic materials present different transmittances for visible and blue light, thus they should be indicated according to their esthetic and required luting procedures. The dental team should acquire knowledge on the technology and materials, working synergistically with digital technology resources to provide more accurate and predictable treatments for the patient.

PUBLICATION 1

Original Article:

https://www.ncbi.nlm.nih.gov/pubmed/?term=Can+lithium+disilicate+ceramic+crowns++be+fabricated+on+the+basis+of+CBCT+data%3F

Can lithium disilicate ceramic crowns be fabricated on the basis of CBCT data? Kauling AEC, Keul C, Erdelt K, Kühnisch J,Güth JF. Clin Oral Investig. 2019 Feb 6. doi: 10.1007/s00784-019-02802-6. [Epub ahead of print]

ABSTRACT:

OBJECTIVES:

Evaluating the fit of CAD/CAM lithium disilicate ceramic crowns fabricated on basis of direct and indirect digitalization of impressions by CBCT or of dental casts.

MATERIAL AND METHODS:

A metal model with a molar chamfer preparation was digitized (n = 12 per group) in four ways: IOS-direct digitalization using an Intra-Oral scanner (CS3600), cone-beam computed tomography scan (CBCT 1)-indirect digitalization of impression (CBCT-CS9300), CBCT 2-indirect digitalization of impression (CBCT-CS8100), and Extra-Oral scanner (EOS)-indirect digitalization of gypsum-cast (CeramillMap400). Accuracy of 3D datasets was evaluated in relation to a reference dataset by best-fit superimposition. Marginal fit of lithium disilicate crowns after grinding was evaluated by replica technique. Significant differences were detected for 3D accuracy by Mann-Whitney U and for fit of crowns by One-way ANOVA followed by Scheffe's post hoc ($p = 0.05$).

RESULTS:

3D analysis revealed mean positive and negative deviations for the groups IOS (- 0.011 ± 0.007 mm/0.010 ± 0.003 mm), CBCT 1 (- 0.046 ± 0.008 mm/0.093 ± 0.004 mm), CBCT 2 (- 0.049 ± 0.030 mm/0.072 ± 0.015 mm), and EOS (- 0.023 ± 0.007 mm/0.028 ± 0.007 mm). Marginal fit presented the results IOS (0.056 ± 0.022 mm), CBCT 1 (0.096 ± 0.034 mm), CBCT 2 (0.068 ± 0,026 mm), and EOS (0.051 ± 0.017 mm).

CONCLUSIONS:

The marginal fit of EOS and IOS, IOS and CBCT 2, and CBCT 2 and CBCT 1 showed statistical differences. The marginal fit of CBCT 1 and CBCT 2 is within the range of clinical acceptance; however, it is significant inferior to EOS and IOS.

CLINICAL RELEVANCE:

The use of a CBCT enables clinicians to digitize conventional impressions. Despite presenting results within clinical acceptable levels, the CBCT base method seems to be inferior to Intra-Oral scans or to scanning gypsum models regarding the resulting accuracy and fit.

KEYWORDS:

Cone-beam computed tomography; Digital impression; Direct digitalization; Fit; Indirect restoration.

PUBLICATION 2

Original Article:

https://www.ncbi.nlm.nih.gov/pubmed/?term=Transmission+of+light+in+the+visible+spectrum+(400-700+nm)+and++blue+spectrum+(360-540+nm)+through+CAD%2FCAM+polymers.

Transmission of light in the visible spectrum (400-700 nm) and blue spectrum (360-540 nm) through CAD/CAM polymers. Güth JF, Kauling AEC, Ueda K, Florian B, Stimmelmayr M

Clin Oral Investig. 2016 Dec;20(9):2501-2506. doi: 10.1007/s00784-016-1755-x.

ABSTRACT:

OBJECTIVES:

CAD/CAM-fabricated long-term temporary restorations from high-density polymers can be applied for a wide range of indications. Milled from monolithic, mono-colored polymer blocks, the translucency of the material plays an important role for an esthetically acceptable result. The aim of this study was to compare the transmittance through visible light and blue light of CAD CAM polymers to a glass-ceramic material of the same color.

MATERIALS AND METHODS:

Ambarino High-Class (AM), Telio-CAD (TC), Zenotec PMMA (ZT), Cercon base PMMA (CB), CAD Temp (CT), Artbloc Temp (AT), Polycon ae (PS), New Outline CAD (NC), QUATTRO DISK Eco PMMA (GQ), Lava Ultimate (LU), and Paradigm MZ 100 (PA) were employed in this study using the feldspathic glass-ceramic Vita Mark II (MK) as control group. Using a spectrophotometer, the overall light transmittance was measured for each material (n = 40) and was calculated as the integration (t c (λ) dλ [10-5]) of all t c values for the wavelengths of blue light (360-540 nm). Results were compared to previous data of the authors for visible light (400 to 700 nm).

RESULTS:

Wilcoxon test showed significant differences between the light transmittance of visible and blue light for all materials.

CONCLUSION:

CAD/CAM polymers showed different translucency for blue and visible light. This means clinicians may not conclude from the visible translucency of a material to its permeability for blue light. This influences considerations regarding light curing.

CLINICAL RELEVANCE:

CAD/CAM polymers need to be luted adhesively; therefore, clinicians should be aware about the amount of blue light passing through a restoration.

KEYWORDS:

CAD/CAM; High-performance polymers; Light curing; Light-transmittance; Long-term temporaries; Optical properties (4–6)

PUBLICATION 3

Original Article:

https://www.ncbi.nlm.nih.gov/pubmed/?term=Virtual+simulation+of+periodontal+surgery+including+presurgical++CAD%2FCAM+fabrication+of+tooth-colored+removable+splints++on+the+basis+of+CBCT+data%3A+a+case+report.

Virtual Simulation of Periodontal Surgery Including Presurgical CAD/CAM Fabrication of Tooth-Colored Removable Splints on the Basis of CBCT Data: A Case Report. Güth JF, Kauling AEC, Schweiger J, Kühnisch J, Stimmelmayr M. Int J Periodontics Restorative Dent. 2017 Nov/Dec;37(6):e310-e320. doi: 10.11607/prd.2769.

ABSTRACT

Innovative digital diagnostic, design, and manufacturing technologies combined with high-performance polymers offer new possibilities to facilitate complex interdisciplinary treatment procedures. This article reports on the interaction of different digital technologies, from presurgical digital simulation of periodontal surgery to final prosthodontic rehabilitation, in a case of amelogenesis imperfecta in a 17-year-old girl. The aim was to digitally determine the

treatment outcome by three-dimensional simulation of the soft tissue removal and to create computer-aided design/computer-assisted manufacture tooth-colored splints before the clinical treatment. The case report shows the synergy of the combination of multiple digital technologies for a predictable periodontal and prosthetic treatment outcome.

REFERENCES

1. Christensen GJ. The state of fixed prosthodontics impressions: room for improvement. J Am Dent Assoc 2005,136:343–346.
2. Christensen GJ. Will digital impressions eliminate the current problems with conventional impressions? J Am Dent Assoc 2008,139:761–763.
3. Bedi A, Michalakis KX, Hirayama H, Stark PC. The effect of different investment techniques on the surface roughness and irregularities of gold palladium alloy castings. J Prosthet Dent 2008,99:282-6.
4. Olivera AB, Saito T. The effect of die spacer on retention and fitting of complete cast crowns. J Prosthodont 2006,15:243-9.
5. Fonseca JC, Henriques GE, Sobrinho LC, de Goes MF. Stress-relieving and porcelain firing cycle influence on marginal fit of commercially pure titanium and titanium aluminum-vanadium copings. Dent Mater 2003,19:686-91.
6. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2008,204:505-11.
7. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J. 2009,28:44-56.
8. Alghazzawi TF. Advancements in CAD/CAM technology: Options for practical implementation. J Prosthodont Res. 2016,60:72-84.
9. Kauling AEC, Keul C, Erdelt K, Kühnisch J, Güth JF. Can lithium disilicate ceramic crowns be fabricated on the basis of CBCT data? Clin Oral Investig. 2019 Feb 6. doi: 10.1007/s00784-019-02802-6. [Epub ahead of print]
10. Güth JF, Kauling AEC, Schweiger J, Kühnisch J, Stimmelmayr M. Virtual simulation of periodontal surgery including presurgical CAD/CAM fabrication of tooth-colored removable splints on the basis of CBCT data: a case report. Int J Periodontics Restorative Dent 2017,37:e310–e320.
11. Hwang HS, Choe SY, Hwang JS, Moon DN, Hou Y, Lee WJ, Wilkinson C. Reproducibility of facial soft tissue thickness measurements using cone-beam CT images according to the measurement methods. J Forensic Sci 2015,60:957–965.
12. Şeker E, Ozcelik TB, Rathi N, Yilmaz B. Evaluation of marginal fit of CAD/CAM restorations fabricated through cone beam computerized tomography and laboratory scanner data. J Prosthet Dent 2016,115:47–51.
13. Robben J, Muallah J, Wesemann C, Nowak R, Mah J, Pospiech P, Bumann A. Suitability and accuracy of CBCT model scan: an in vitro study. Int J Comput Dent 2017,20:363–375.
14. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971,131:107–111.
15. Janenko C, Smales RJ Anterior crowns and gingival health. Australia Dent J 1979, 24:225–230.
16. Belser UC, MacEntee MI, Richter WA. Fit of three porcelain-fused-to-metal marginal designs in vivo: a scanning electron microscope study. J Prosthet Dent 1985, 53:24–29.
17. Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress and Procera crowns. Int J Prosthodont 1997,10:478–484.
18. Molin M, Karlsson S. The fit of gold inlays and three ceramic inlay systems. A clinical in vitro study. Acta Odontol Scand 1993,51:201–6.
19. Sen N, Us YO. Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthet Dent. 2018,119:593-599.

20. Furtado de Mendonca A, Shahmoradi M, Gouvêa CVD, De Souza GM, Ellakwa A. Microstructural and Mechanical Characterization of CAD/CAM Materials for Monolithic Dental Restorations. J Prosthodont. 2019,28:e587-e594.
21. Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS. Technical aspects of dental CBCT: state of the art. Dentomaxillofac Radiol 2015, 44:20140224.
22. Lee CH, Ryu JH, Lee YH, Yoon KH. Reduction of radiation exposure by lead curtain shielding in dedicated extremity cone beam CT. Br J Radiol 2015, 88:20140866.
23. Kang SR, Lee WJ, Woo SY, Kim DS, Yi WJ. Radiation dose reduction in CBCT imaging using K-edge filtering and energy weighting. Conf Proc IEEE Eng Med Biol Soc 2014, 5137–5140.
24. Silva LHD, Lima E, Miranda RBP, Favero SS, Lohbauer U, Cesar PF. Dental ceramics: a review of new materials and processing methods. Braz. Oral Res. 2017,31:e58, 133-146.
25. Alt V, Hannig M, Wostmann B, Balkenhol M. Fracture strength of temporary fixed partial dentures: CAD/CAM versus directly fabricated restorations. Dent Mater 2011, 27:339–347.
26. Goncu Basaran E, Ayna E, Vallittu PK, Lassila LV. Load- bearing capacity of handmade and computer-aided design–computer-aided manufacturing-fabricated three-unit fixed dental prostheses of particulate filler composite. Acta Odontol Scand 2011,69:144–150.
27. Stawarczyk B, Ender A, Trottmann A, Özcan M, Fischer J, Hämmerle CH. Load-bearing capacity of CAD/CAM milled polymeric three-unit fixed dental prostheses: effect of aging regimens. Clin Oral Investig 2012,16:1669–1677.
28. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: historical roots and current perspectives. J Prosthet Dent 1996,75:18–32.
29. Güth JF, Kauling AEC, Ueda K, Florian B, Stimmelmayr M. Transmission of light in the visible spectrum (400-700 nm) and blue spectrum (360-540 nm) through CAD/CAM polymers. Clin Oral Investig. 2016,20:2501-2506.
30. Flury S, Lussi A, Hickel R, Ilie N. Light curing through glass ceramic with a second- and a third-generation LED curing unit: effect of curing mode on the degree of conversion of dual-curing resin cements. Clin Oral Investig 2014,18:809–818.
31. Ilie N, Stawarczyk B. Quantification of the amount of light passing through zirconia: the effect of material shade, thickness, and curing conditions. J Dent 2014,42:684–690.
32. Ilie N, Stawarczyk B. Quantification of the amount of blue light passing through monolithic zirconia with respect to thickness and polymerization conditions. J Prosth Dent 2015,113:114–121.
33. Güth JF, Almeida e Silva JS, Ramberger M, Beuer F, Edelhoff D. Treatment concept with CAD/CAM-fabricated high-density polymer temporary restorations. J Esthet Restor Dent 2012,24:310–318
34. Güth JF, Almieda e Silva JS, Beuer F, Edelhof D. Enhancing the predictability of complex rehabilitation with a removable CAD/ CAM-fabricated long-term temporary prosthesis: a clinical report. J Prosth Dent 2012,197:1–6.
35. Edelhoff D, Beuer F, Schweiger J, Stimmelmayr M, Güth JF. CAD/CAM-generated high-density polymer restorations fort the pretreatment of complex cases: a case report. Quintessence Int 2012,43:457–467.

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