



CAD/CAM produces dentures with improved fit

Otto Steinmassl¹ · Herbert Dumfahrt² · Ingrid Grunert² · Patricia-Anca Steinmassl² 

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Abstract

Objectives Resin polymerisation shrinkage reduces the congruence of the denture base with denture-bearing tissues and thereby decreases the retention of conventionally fabricated dentures. CAD/CAM denture manufacturing is a subtractive process, and polymerisation shrinkage is not an issue anymore. Therefore, CAD/CAM dentures are assumed to show a higher denture base congruence than conventionally fabricated dentures. It has been the aim of this study to test this hypothesis.

Materials and methods CAD/CAM dentures provided by four different manufacturers (AvaDent, Merz Dental, Whole You, Wieland/Ivoclar) were generated from ten different master casts. Ten conventional dentures (pack and press, long-term heat polymerisation) made from the same master casts served as control group. The master casts and all denture bases were scanned and matched digitally. The absolute incongruences were measured using a 2-mm mesh.

Results Conventionally fabricated dentures showed a mean deviation of 0.105 mm, $SD = 0.019$ from the master cast. All CAD/CAM dentures showed lower mean incongruences. From all CAD/CAM dentures, AvaDent Digital Dentures showed the highest congruence with the master cast surface with a mean deviation of 0.058 mm, $SD = 0.005$. Wieland Digital Dentures showed a mean deviation of 0.068 mm, $SD = 0.005$, Whole You Nexteeth prostheses showed a mean deviation of 0.074 mm, $SD = 0.011$ and Baltic Denture System prostheses showed a mean deviation of 0.086 mm, $SD = 0.012$.

Conclusions CAD/CAM produces dentures with better fit than conventional dentures.

Clinical Relevance The present study explains the clinically observed enhanced retention and lower traumatic ulcer-frequency in CAD/CAM dentures.

Keywords CAD/CAM dentures · Complete dentures · Denture fit · Denture base congruence · Dental materials · PMMA resin

Introduction

Removable complete dentures are the least invasive and most cost-effective option for the prosthodontic rehabilitation of edentulous patients [1]. A crucial factor determining the quality of removable dentures is the denture fit [2]. Well-fitting dentures show a higher primary wearing comfort and reduce the occurrence of traumatic ulcers [3]. Most of all, tissue-congruent denture fit is the most important key factor for good

retention in removable complete dentures [4]. Denture retention, again, affects the masticatory performance and speaking ability and hereby has a strong impact on the patients' quality of life [5]. Therefore, achieving maximal tissue congruence should be one of the main goals in complete denture fabrication [6].

Before the introduction of CAD/CAM technology into removable prosthodontics, the congruence between denture base and denture-bearing tissues was always impeded by the resin's polymerisation shrinkage [7]. The shrinkage causes distortions of the denture base and therefore has a negative impact on fit and retention of removable complete dentures [8–10]. In CAD/CAM fabrication, on the other hand, the manufacturing process is subtractive: The denture bases are milled from fully polymerised acrylic resin pucks [11] and are therefore not subject to shrinkage or distortion phenomena anymore [12, 13].

It has been the aim of the present study to investigate if CAD/CAM fabricated denture bases have a higher

✉ Patricia-Anca Steinmassl
patricia.steinmassl@tirol-kliniken.at

¹ University Hospital for Cranio-Maxillofacial and Oral Surgery, Medical University of Innsbruck, MZA, Anichstr. 35, A-6020 Innsbruck, Austria

² University Hospital for Dental Prosthetics and Restorative Dentistry, Medical University of Innsbruck, MZA, Anichstr. 35, A-6020 Innsbruck, Austria

congruence with the denture-bearing tissues than conventionally processed denture bases. Therefore, the null hypothesis for this study was that there is no difference in the precision of fit between CAD/CAM fabricated and conventional dentures.

Materials and methods

Study specimens

The present study is an *in vitro* study. Maxillary study casts originating from ten edentulous patients served as master casts. The specimen number was chosen in analogy with similar studies [14, 15]. The study casts included different anatomical situations: moderate to strong alveolar resorption with or without undercuts and high and shallow palates, as well as granular and smooth mucosal surfaces. Five dentures were fabricated from each of these ten master casts: four different CAD/CAM dentures and one conventional denture. The four different CAD/CAM dentures per cast were provided by the four CAD/CAM denture manufacturers (AvaDent Digital dentures [Global Dental Science Europe BV, Tilburg, Netherlands], Baltic Denture System [Merz Dental GmbH, Lütjenburg, Germany], Whole You Nexteeth [Whole You Inc., San Jose, US], Wieland Digital Dentures [Wieland Dental + Technik GmbH & Co. KG, Pforzheim, Germany/Ivoclar Vivadent AG, Schaan, Liechtenstein]). Each company produced one denture per master cast.

The anatomical information required for manufacturing the study dentures was obtained from master cast scans by AvaDent, Baltic Denture System and Wieland Digital Dentures. The Whole You Nexteeth system could not process master cast scans. Therefore, impressions of the master casts had to be generated using Imprint 4 Super Quick Heavy and Light polyvinylsiloxane impression material (3 M Deutschland GmbH, Neuss, Germany) and DENTCA impression trays (Dentca INC, Torrance, USA). The impression scans could then be integrated into the Whole You Nexteeth digital workflow.

The ten conventionally manufactured dentures fabricated from each of the ten original master casts served as a control group. The conventional dentures were made in compressed mould technique. For the mould, class IV gypsum (SheraPure, SHERA Werkstoff-Technologie GmbH & Co. KG, Lemförde, Germany) was processed according to the manufacturer's instructions and then isolated with a plaster-against-resin separating fluid (Separating Fluid, Ivoclar Vivadent, Schaan, Liechtenstein). The denture bases were made from heat polymerising resin (Candulor Aesthetic Red®, Candulor AG, Glattpark, Switzerland) in the recommended long-term heat polymerisation cycle (75 °C water bath for 8.5 h). All study specimens were finished only on the oral surfaces, while the mucosa-sided surfaces were left unfinished, as customary

in the clinical use. All dentures were stored in sealed beakers containing 200 ml of deionised water at 37.0 °C for 7 days in darkness before analysis.

Digital scanning and matching procedures

Prior to the fabrication of the conventional dentures, which would involve the casts' destruction, the master casts were scanned using a 7Series Dental Wings scanner (Dental Wings Inc., Montreal QC, Canada), after applying a thin and homogenous layer of Shera scanspray (SHERA Werkstoff-Technologie GmbH & Co. KG, Lemförde, Germany). All scanning procedures were performed by the same trained examiner in the climate-controlled laboratory of the Department of Dental Prosthetics and Resorative Dentistry of the Medical University of Innsbruck. The generated digital data (3D meshes) was processed in STL-format. The same procedure was applied to the mucosal surfaces of each study denture. After standardised cropping of the meshes, the mucosal denture-base surfaces were matched with the master cast surfaces using the reverse-engineering software GOM Inspect 2016 (GOM, Braunschweig, Germany), by the same trained examiner (Fig. 1). The measurement points were set at minimal distance, resulting in a 2-mm mesh. The unsigned absolute mismatch-values were used to avoid the neutralisation of positive and negative values. Besides calculating the overall mean mismatch, the master cast surface was also divided in five functionally relevant sections (posterior palatal seal, anterior and lateral border seal, alveolar ridge, tubera maxillaria and palate) to evaluate the region-specific mismatches.

Following these analyses, all specimens were submitted to a thermocycling protocol simulating 6 months of intraoral use [16]: The dentures underwent 5000 cycles of alternating immersion in deionised water with 5 and 55 °C. After thermocycling, the scanning and matching procedures were repeated, following the aforementioned protocol.

Statistics

The data was handled using SPSS Statistics 22 (IBM, Armonk NY, USA) and R 3.3.1 (R Foundation for statistical computing, Vienna, Austria). The means of absolute deviations of each denture or denture region were used. The data was assessed by inspection of box plots regarding outliers. The Shapiro-Wilk's test and QQ-plots were used to test the data's normal distribution. Means and standard deviations (SD) were calculated, as well as 95%-confidence intervals. To explore if there were statistically significant differences between conventional dentures and the different CAD/CAM-manufactured dentures, one-way repeated measures ANOVA was performed in conjunction with post hoc analysis and Bonferroni correction. To determine the statistical differences between the different denture regions, a one-way Welch

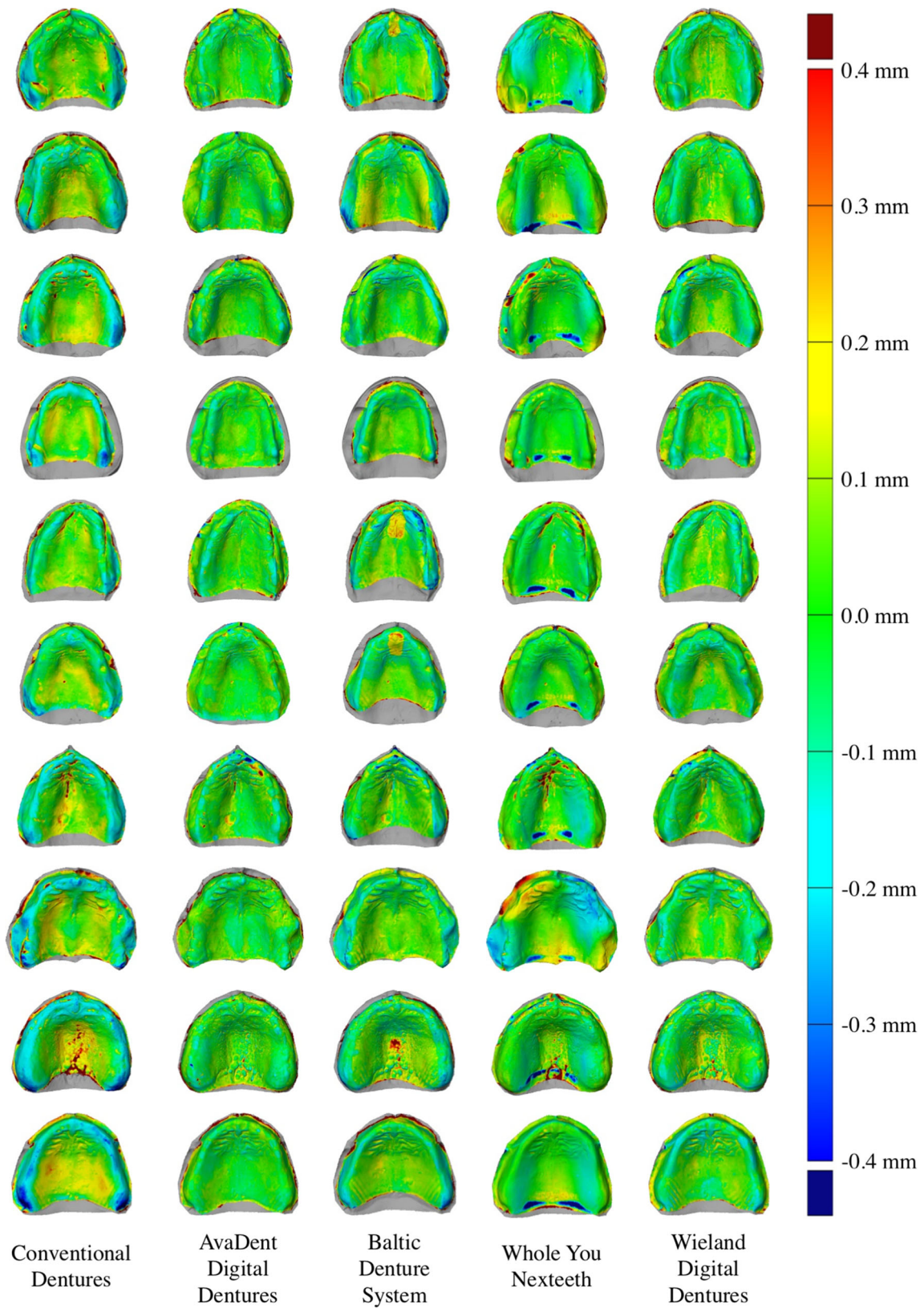


Fig. 1 Colour maps indicating the incongruence between the mucosal denture bases and the corresponding master cast surfaces

ANOVA was conducted together with Games-Howell post hoc analysis.

The significance level for statistical tests was set at $\alpha = 0.05$. $\alpha = 0.01$ was set as the level of high statistical significance.

Results

Overall denture fit (Table 1, Fig. 2)

The deviations between mucosal denture surfaces and the corresponding master cast surfaces were measured at an average of 650.2, $SD = 86.1$ measuring points per denture. There were no outliers in the data, and the deviation values were normally distributed. Conventionally fabricated dentures showed a mean deviation of 0.105 mm, $SD = 0.019$ from the master cast. All CAD/CAM fabricated dentures had lower mean denture base incongruences than the conventionally fabricated dentures. AvaDent Digital Dentures showed the greatest congruence with the master cast surface with a mean deviation of 0.058 mm, $SD = 0.005$. Wieland Digital Dentures showed a mean deviation of 0.068 mm, $SD = 0.005$, Whole You Nexteeth prostheses showed a mean deviation of 0.074 mm, $SD = 0.011$ and Baltic Denture System prostheses showed a mean deviation of 0.086 mm, $SD = 0.012$. The mean values, standard deviations, 95%-confidence intervals and the ranges of fit are listed in Table 1 and illustrated in Fig. 2.

The mean incongruence values indicated statistically highly significant differences among the manufacturers, $F(1.873, 16.855) = 28.878$, $p < 0.0005$, partial $\eta^2 = 0.762$.

AvaDent Digital Dentures, Wieland Digital Dentures and Whole You Nexteeth prostheses showed a highly significantly better denture base congruence than the conventional dentures. Baltic Denture System prostheses also showed a more precise fit than the conventionally fabricated dentures, but the mean value difference was not statistically significant.

Compared to the conventional dentures, AvaDent Digital Dentures had a difference of mean misfit of 0.047 mm (95% CI [0.023, 0.071], $p < 0.0005$), Wieland Digital Dentures of 0.037 mm (95% CI [0.016, 0.058], $p = 0.001$) and Whole You Nexteeth dentures of 0.031 mm (95% CI [0.008, 0.054], $p = 0.008$). The fit of all three CAD/CAM systems was statistically highly significantly better than in the control group. The mean misfit of Baltic Denture System was 0.019 mm (95% CI [-0.007, 0.046]) smaller than in conventional dentures, but this difference was, as aforementioned, not statistically significant ($p = 0.258$). Therefore, the null hypothesis had to be rejected.

Region-specific misfit (Table 2, Fig. 3)

The functional regions with the most precise fit in conventional and almost all CAD/CAM dentures were the alveolar ridge

and the palate. The greatest extent of misfit was found in the posterior palatal seal regions and the anterior and lateral seal regions. AvaDent dentures and Wieland Digital Dentures, which had the highest precision of fit, also showed rather low deviations in the posterior palatal seal regions (0.057 mm, $SD = 0.005$ and 0.071 mm, $SD = 0.008$) and the anterior and lateral seal regions (0.084 mm, $SD = 0.017$ and 0.088 mm, $SD = 0.011$, respectively). Whole You Nexteeth prostheses showed the highest values of deviation in the posterior palatal seal region (0.166 mm, $SD = 0.044$). The region-specific mean misfit values and 95%-confidence intervals are listed in Table 2. Figure 3 shows a diagram of the incongruence values of conventional and different CAD/CAM dentures, broken down to different regions of interest.

The differences in the denture base congruence between the various functional regions were statistically highly significant in conventional dentures and also in all CAD/CAM dentures ($p < 0.01$). The congruence in the palatal region was statistically significantly higher than in the anterior and lateral seal region, in all groups ($p < 0.05$). In Whole You Nexteeth prostheses, the posterior palatal seal region showed a statistically significantly higher misfit than all other regions ($p < 0.05$).

Post-thermocycling misfit

Thermocycling did not have a statistically significant impact on the precision of fit. Not only were the changes in fit within the imprecision of the scanning and matching processes, but there was also no reproducible trend towards increased or diminished precision of fit, neither for conventional, nor for CAD/CAM dentures.

Discussion

Experimental setup

The present study was designed to evaluate the denture fit in a clinically relevant setting. The master cast samples represented a broad range of different clinical alveolar ridge configurations. Even extreme anatomical situations were represented. By generating the study dentures directly from the same master casts, uncontrolled bias caused by the impression was avoided for the AvaDent Digital Dentures, Baltic Denture System prosthesis, Wieland Digital Dentures and for the conventionally fabricated dentures. A direct scan of the master casts was not possible for the Whole You Nexteeth dentures; therefore, impressions of the master casts were mandatory. Perhaps the fit of Whole You Nexteeth dentures had been even more precise if the Whole You software had been able to process master cast scans the way the other companies did.

Table 1 Misfit between mucosal denture base and master cast surface

Manufacturer	Mean denture base incongruence (mm), standard deviation	[95%-CI] of mean incongruence (mm)	Minimum incongruence (mm)	Maximum incongruence (mm)	Mean number of measurement points per denture
AvaDent Digital Dentures	0.058, SD = 0.005	[0.054; 0.062]	0.049	0.066	664.1
Baltic Denture System	0.086, SD = 0.012	[0.077; 0.094]	0.065	0.107	619.7
WholeYou Nexteeth	0.074, SD = 0.011	[0.067; 0.082]	0.054	0.089	672.4
Wieland Digital Dentures	0.068, SD = 0.005	[0.064; 0.072]	0.058	0.075	653.4
Conventional Dentures	0.105, SD = 0.019	[0.091; 0.119]	0.086	0.141	641.5

In our experimental setup, the congruence of the mucosal denture base surface of the CAD/CAM dentures was determined mainly by two factors: the scanner resolution and the precision of the milling process. According to the technical data sheet, the dental wings 7Series scanner has an accuracy of 15 μm [17], and in vitro studies have shown that surface pre-treatment with scanning powder does not impair the scanning accuracy significantly [18], probably due to the aerosol sprays’ small particle sizes of around 5 μm [19]. Since the magnitude of the deficiencies of fit was above the scanner’s accuracy in the present study, the experimental setup appears to be appropriate for detecting differences within the necessary level of measurement. In clinical practice, the impression protocol will also be a relevant factor. Since there is no evidence-based gold standard for impression-taking in removable denture prosthodontics and every impression-taking procedure contains a multiplicity of poorly controllable variables, such as air trapping or contact pressure, the experimental setup used in the present study avoided impression-taking, when possible.

Study findings

While all conventional resin processing protocols have to deal with polymerisation shrinkage, the milling process used in CAD/CAM dentures is subtractive. The denture base is being milled in its final dimension from an industrially polymerised resin puck, and processing-related volumetric changes of the denture base do not occur anymore. Therefore, the finding that all CAD/CAM fabricated dentures showed a higher congruence with the master cast surface is little surprising. Until now, only two studies have investigated the precision of CAD/CAM denture fit, both examining only AvaDent Digital Dentures and reporting controversial findings: While Goodacre et al. reported an enhanced fit of AvaDent Digital Dentures compared to different conventionally manufactured dentures [14], Srinivasan and Cantin, found that the precision of fit was better in the conventional denture group than in AvaDent Digital Dentures [15]. Our results support

Fig. 2 Overall misfit between denture bases and master cast surfaces

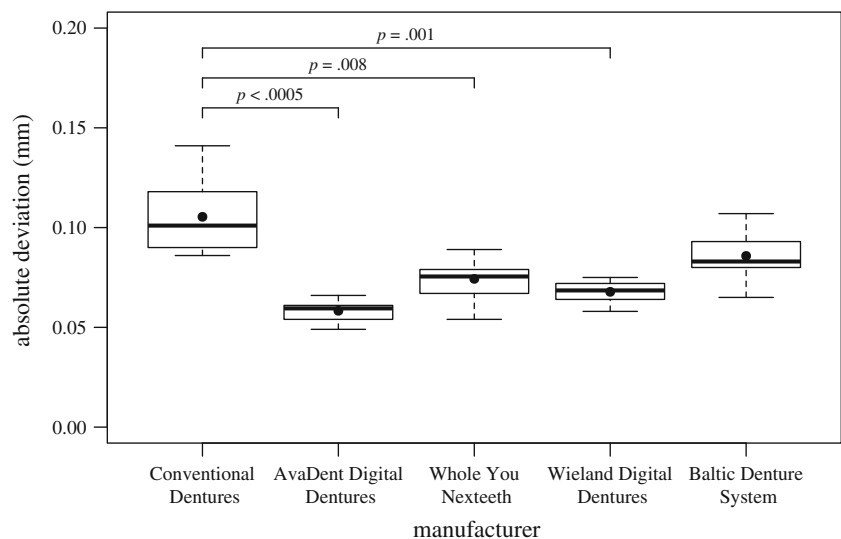


Table 2 Region-specific misfit between mucosa-sided denture base and master cast surface

	Posterior palatal seal	Anterior and lateral border seal	Tubera maxillaria	Alveolar ridge	Palate
	Mean (mm), [95%-CI]	Mean (mm), [95%-CI]	Mean (mm), [95%-CI]	Mean (mm), [95%-CI]	Mean (mm), [95%-CI]
AvaDent Digital Dentures	0.057 [0.054; 0.061]	0.084 [0.072; 0.096]	0.055 [0.051; 0.060]	0.059 [0.055; 0.063]	0.045 [0.040; 0.051]
Baltic Denture System	0.094 [0.079; 0.108]	0.115 [0.090; 0.139]	0.087 [0.075; 0.100]	0.080 [0.072; 0.088]	0.060 [0.051; 0.070]
WholeYou Nexteeth	0.166 [0.135; 0.197]	0.102 [0.080; 0.124]	0.069 [0.056; 0.082]	0.071 [0.054; 0.087]	0.060 [0.041; 0.080]
Wieland Digital Dentures	0.071 [0.065; 0.076]	0.088 [0.080; 0.096]	0.066 [0.060; 0.072]	0.069 [0.064; 0.067]	0.063 [0.057; 0.068]
Conventional Dentures	0.108 [0.095; 0.121]	0.127 [0.114; 0.121]	0.109 [0.090; 0.128]	0.088 [0.074; 0.102]	0.086 [0.072; 0.100]

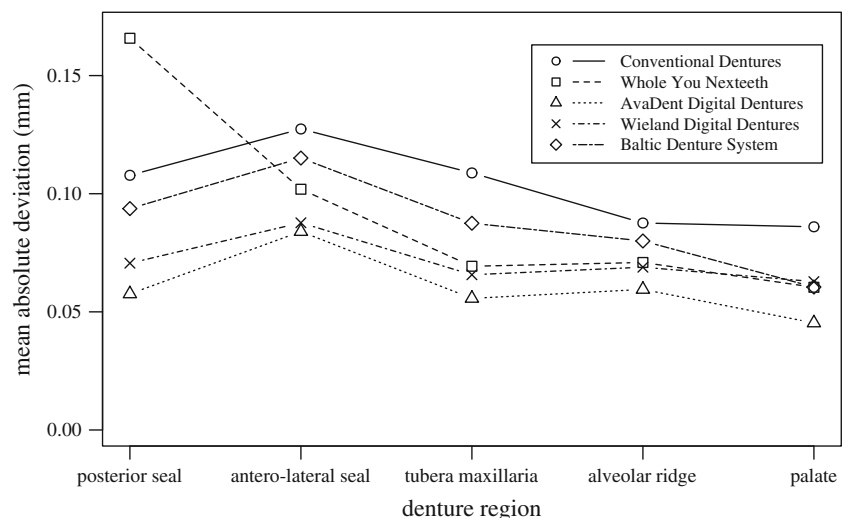
Goodacre's findings, but the mean incongruence values found in the present study are higher than the previously reported values, which are between 0.0023 and 0.0168 mm [14] or 0.007 and 0.019 mm [15]. A possible explanation may be that Srinivasan used a different protocol for evaluating the extent of incongruences and also a different matching software [15]. Goodacre used the same matching software as we did, but with a broader mesh (only 60 measuring points per denture) [14]. From all CAD/CAM denture systems, AvaDent Digital Dentures had the highest precision of fit in the present study, although all examined CAD/CAM dentures performed better than the conventional dentures. Nevertheless it must be stated that the mean incongruences of the conventionally fabricated dentures were already very low.

In respect to the anatomical feature-related differences, the region-specific analyses showed that although both conventional and CAD/CAM-fabricated dentures had similar vulnerabilities, the extent of misfit was lower in CAD/CAM dentures, and also the region-specific findings for AvaDent dentures were in concordance with Goodacre's [14] and Srinivasan's reports [15]. The mechanisms causing the misfits, however, differ

between CAD/CAM and the conventional dentures. While the conventional denture processing has to face polymerisation shrinkage, reproducing undercut regions may be a major challenge for the CAM-milling machine. This hypothesis is supported by the finding that all CAD/CAM denture systems had some, even though small, trouble reproducing the anterior and lateral seal region, which often involved undercut regions beneath the alveolar crest in the present study.

Clinical relevance

The intended purpose of the present study was to give an overview over the prospective clinical performance of the different currently available CAD/CAM systems. The investigated CAD/CAM systems were able to reproduce the master cast surfaces very precisely and even preciser than the conventional manufacturing protocol. The findings of the present study explain the observed clinical excellence of CAD/CAM-fabricated dentures regarding retention [20], even with the recommended reduced adaption and impression protocols.

Fig. 3 Region-specific misfit

Conclusion

Computer-aided design and manufacturing produces dentures with higher tissue congruence than conventional denture fabrication. AvaDent Digital Dentures, Whole You Nexteeth prosthesis and Wieland Digital Dentures have a significantly higher precision of denture base fit than the conventional dentures. It is therefore plausible that CAD/CAM dentures will show better clinical retention, as well as a reduced frequency of denture-related traumatic ulcers. Digital design and automatic processing are able to compensate some manual-processing-related sources of failure. Nevertheless, meticulous adjustment and profound prosthodontic knowledge remain unreplaceable for a successful prosthodontic rehabilitation.

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Compliance with ethical standards

Conflict of interest Ingrid Grunert reports personal fees from Mitsui Chemicals, outside the submitted work. Otto Steinmassl declares that he has no conflict of interest. Herbert Dumfahrt declares that he has no conflict of interest. Patricia-Anca Steinmassl reports personal fees from Candulor AG, outside the submitted work.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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