A crucial prerequisite for the fabrication of prosthetic dentures by a dental technician is the replication of a patient’s intraoral structure for transfer to the dental laboratory. It is of the utmost importance that all anatomical conditions are reproduced as accurately and in as much detail as possible because this is the only way to ensure the production of high-quality, accurately fitting prosthetic restorations. Historically, conventional impressions were the only option for reproducing the necessary structures in order to fabricate correctly fitting dentures. However, this technique, as well as the subsequent fabrication of the restoration, are limited by methodologic and material errors.1,2 Deficiencies such as expansion, shrinkage, or deformation of the impression or plaster material cannot be avoided with the available impression materials or trays.3 Consequently, in recent years, intensive research has been conducted with the aim of discovering an alternative approach that could reproduce all relevant anatomical features of the patient’s oral cavity in at least equivalent detail to that achieved with conventional impressions.

Comparison of Digital and Conventional Impressions Based on the 3D Fit of Crowns

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Recent advances and innovative technologies have made it possible to make digital impressions with scannable impression materials and a light-optical 3D scanner. This approach eliminates the need to fabricate a plaster master model, thus avoiding a number of potential sources of error, including the pouring of the plaster into the impression, the drilling and fixing of pins in the plaster model, and the sawing of the model.

To overcome further potential inaccuracies inherent to conventional technology, the workflow is becoming increasingly digitized. Various intraoral scanning systems have become available on the market; in the course of the present study, the TRIOS system (3Shape), based on the principles of confocal microscopy, became available for image acquisition. The primary feature of this intraoral scanner is that the object to be scanned, the optical system, and the camera are in defined relationships to each other. The light source generates an illumination pattern to produce light oscillation on the object, and it should be noted that the spatial relationship between the object and the scanning head always remains constant. As a result, 2D images are generated at several points on the focal plane, ultimately producing a large number of images within a short time. Another advantage of this scanner is the true-color reproduction of the scanned structures, which makes it easy to distinguish between the soft tissue and the tooth structure when planning dental prostheses. In addition, this system offers the possibility of powder-free scanning, unlike other brands, which require powdering the object.

Furthermore, in contrast to the conventional impression method, the principle of direct intraoral digitization provides a real-time display of the relevant structures, which allows for examinations and analyses of the preparations directly on the 3D digital model. Finally, both the fabrication and the insertion of the prosthetic restoration can be performed in a single session. This system has numerous other advantages, including the easy and selective reproducibility of scans, the material savings, and the ease of use. However, its decisive advantages are twofold: (1) the workflow can significantly be shortened; and (2) it is no longer necessary to digitize the impression separately. Consequently, additional sources of error can be avoided, which ultimately has a positive effect on the fit of the resulting restoration.

Only a few studies have compared these three methods: making impressions from a scannable material; making direct intraoral digital impressions with an intraoral scanner; and making impressions with the conventional technique, which has been used to date. The present in vitro study aimed to verify and compare the precision of these three impression approaches. For this purpose, impressions were taken using the different techniques, and corresponding crown copings were fabricated with an identical CAD/CAM process. Subsequently, the internal fit and accuracy of the margins of the restorations were assessed with a 3D scanning procedure. The null hypothesis was that all test specimens manufactured based on the three impression methods would show identical accuracies of fit.

MATERIALS AND METHODS

In the first step, a cobalt-chromium (Co-Cr) master model of a chamfer preparation of the maxillary right first molar was prepared to fit a single crown. A two-step impression was initially taken using silicone (AFFINIS Heavy Body and Light Body, Coltène/Whaledent). The model body was then laterally fitted with two guide elements made of Co-Cr for attachment in order to ensure the same position for all impressions taken. Furthermore, special individual impression trays designed to maintain a distance of 5 mm on all sides between the model die and the tray wall were manufactured. The trays were also provided with a construction guide so that the impressions could be taken guided and without changing position (Fig 1).

From the metal master model, 10 digital impressions were taken with a TRIOS scanner (3Shape), and 20 physical impressions were taken: 10 with a conventional impression material (AFFINIS Precious Heavy and Light Body) with the double-mix technique, and 10 with a scannable material (Identium Medium, Identium Light, Kettenbach).

The impressions in the conventional group (group A; AFFINIS Precious) were poured with class IV gypsum (Fujirock EP Classic super hard plaster, GC). Then, the resulting plaster master casts were given to the CAD/CAM milling/manufacturing center (CADfirst, Brautlach, Germany).
Germany). There, the plaster casts were digitized with a 3D laser scanner (7Series, Dental Wings).

In the scannable material group (group B), a special elastomeric impression material (Identium Scan) designed for optical acquisition with the CAD/CAM process was used with the double-mix technique. Subsequently, the 10 impressions obtained were digitized with an iSeries 3D scanner (Dental Wings). The 3D standard tessellation language (STL) data were also sent to the milling center (CADfirst).

In the intraoral digital group (group C), digital impressions were taken with the cara TRIOS intraoral scanner (3Shape). The optical impression data were converted into STL data with the software integrated in TRIOS-Converter (3Shape). The STL data were then also transmitted to the milling center (CADfirst).

Subsequently, for each impression method, 10 Co-Cr test specimens corresponding to anatomically reduced crown copings were milled with the CAD/CAM procedure at the milling center (CADfirst) based on the respective STL data. DWOS 4.0.1.29805 software provided with the Dental Wings 3Series scanner was used during the design process. The fabricated test specimens were subsequently subjected to a digitization process with a noncontact optical scanner (ATOS Triple Scan, GOM). Since a matte surface is required to avoid reflections with the optical detection of objects, the metal master model and the crown copings were previously sandblasted with aluminum oxide (Al₂O₃). To evaluate the marginal gap, three scans were taken of each specimen according to Holst et al and Matta et al³²,³³ to ensure that the crown copings on the metal master model made of Co-Cr (groups A to C) and the plaster master casts from the conventional impressions (control group, group D) could be correctly positioned on a virtual level (Fig 2). The manufactured crown copings in group A were additionally scanned and measured on the corresponding plaster casts to investigate the accuracy of the laboratory scans (group D).

In summary, the groups were defined as follows:

- **Group A**: Analysis of fit of the crown copings on the metal master model (ie, patient model) fabricated on the basis of conventional impressions and laboratory scans of the plaster casts.
- **Group B**: Analysis of fit of the crown copings on the patient model manufactured on the basis of laboratory scans of the scannable impressions.
- **Group C**: Analysis of fit of the crown copings on the patient model produced on the basis of digital impressions of the model using the intraoral scanner.
- **Group D**: Analysis of fit of the crown copings on the plaster casts (control group) fabricated on the basis of the laboratory scans of the plaster casts.

The Co-Cr master model and the plaster casts were equipped with high-contrast reference points at the base (ATOS, GOM) to facilitate precision during the following scanning process. The crown copings for the different impression methods were first scanned individually in a specially calibrated measuring frame (reference frame, GOM). Subsequently, the test specimens placed on the metal master model were scanned. Finally, the crown copings obtained from the conventional impressions were positioned on the corresponding plaster casts and scanned. During this process, each test specimen was checked by an experienced dentist (R-E.M.) to ensure that it was correctly positioned on the metal master model or plaster master cast. Subsequently, the crown copings were fixed with adhesive wax in order to prevent position changes during the scanning process.

After digitizing the restorations, ATOS software (ATOS Professional, GOM) was used to generate STL data.
These data were then aligned with each other three-dimensionally according to the protocol introduced by Holst et al. This process of superimposition was performed with the local best-fit function, which ensured that the deviations never exceeded 3 µm. Finally, all STL data sets were aligned with each other, resulting in the matched files.

Next, a 3D analysis of the internal and marginal fit was performed by selecting the inner surface of the crown copings (actual value) and calculating the deviations from the reference object, which was the metal master model or one of the plaster casts (target value or CAD mesh). In addition, the actual mesh was cut on a curve at a distance of 1 mm in the direction of the lumen to the inner crown margin, which was located at the preparation margin. Thus, the marginal and internal areas were created to determine the marginal and internal fit. Finally, a surface comparison of these two actual meshes on the target meshes was carried out to ensure that all distance measurements, starting from the inner surface of the crown copings to the die of the metal master model or plaster casts, could be reproduced at all points in the corresponding area. Thus, the deviations of the fabricated test specimens from the reference model could be calculated. The deviations were displayed in the program in numeric (tabular) form and also represented with a false color scale (Fig 3).

In addition to the 3D analysis, a 2D analysis was carried out to assess the edge closure. For this purpose, the virtual complex, consisting of the die of the reference model and the crown coping, was digitally cut into 20 radial sections, 18 degrees per section (Fig 4).

According to the definition of Matta et al and Holmes et al, each of the individual measuring points was subsequently subjected to three different measurements: the absolute marginal discrepancy (xyz), the vertical discrepancy (z), and the horizontal (xy) marginal gap (Fig 5).

Figure 6 illustrates an overview of the workflow in this study.

The R Program (R Core Team) was used for statistical analysis. First, a global group comparison of the crown copings was performed with Kruskal-Wallis test. If a significant result was found, pairwise comparisons with Mann-Whitney U test were performed. The significance level was set at .05.

RESULTS

The accuracy of fit of the crowns on their respective master model and plaster casts was determined in two dimensions as well as in three dimensions. The accuracy of fit of the crown copings on their corresponding metal master models and plaster casts is illustrated in Figs 7 and 8.

Statistical analysis of the 2D results showed that there were no significant differences between groups A, B, and C with regard to the vertical marginal discrepancies (z) between the test specimens and the reference models. In
contrast, group D showed a significantly smaller marginal gap in the vertical plane ($0.007 \pm 0.017 \text{ mm}$) compared to group A ($0.024 \pm 0.005 \text{ mm}; P = .009$).

Furthermore, the horizontal marginal discrepancy ($xy$) of the crown copings in group C ($0.014 \pm 0.003 \text{ mm}$) was significantly lower than groups A, B, and D ($0.024 \pm 0.008$, $0.022 \pm 0.004$, and $0.025 \pm 0.005 \text{ mm}$, respectively; $P < .005$).

Finally, the 2D evaluation also included determination of the absolute marginal discrepancy ($xyz$). The lowest values were found in the crown copings of group C ($0.026 \pm 0.007 \text{ mm}$). In comparison, significantly
larger marginal gaps were found in groups A (0.038 ± 0.011 mm; \( P = .028 \)), B (0.034 ± 0.008 mm; \( P = .043 \)), and D (0.045 ± 0.01 mm; \( P < .001 \)).

The 3D investigation included measurements of the internal and marginal fit. The crown copings in group D showed the best internal fit on the plaster master casts, with the lowest gaps (0.087 ± 0.006 mm) compared to groups A (0.103 ± 0.005 mm), B (0.105 ± 0.01 mm), and C (0.109 ± 0.007 mm; \( P = .001 \)). In addition, group D had a significantly smaller marginal gap (0.028 ± 0.008 mm) than groups A (0.046 ± 0.009 mm; \( P = .015 \)), B (0.09 ± 0.0049 mm; \( P = .005 \)), and C (0.06 ± 0.013 mm; \( P = .015 \)). Furthermore, the marginal deviations were significantly smaller in group A compared to group B (\( P = .025 \)).

**DISCUSSION**

The long-term clinical success of a fixed dental restoration is based on its accuracy of fit. Fit can be influenced by many different factors, including the impression-taking step and other steps performed during the working procedure after the preparation has been completed.\(^{15}\)

The present study examined the accuracy and precision of three different impression techniques that are well known (conventional, digital, and conventional with a scannable material). The influence of these different methods on the restoration fit was examined.

The results showed that the null hypothesis, which stated that all crown copings would fit equally accurately regardless of the impression technique used, could be rejected. Indeed, significant differences were found among the three methods in certain parameters related to fit. For example, the average absolute marginal discrepancy in the 2D analysis was 26 μm in group C, indicating that the digital impression resulted in the lowest deviations of the fabricated crown copings. In this regard, a better fit of the same crown copings in groups A (38 μm) and D (45 μm) on the master model was also observed. Due to the sections defined by the software, which cannot be changed during 2D evaluation, possible errors at the preparation margin of the plaster cast are also measured.\(^5\) However, the results of the absolute marginal discrepancy (\( xyz \)) of these four groups showed that all restorations provided adequate fit, with gaps far smaller than the maximum 120-μm marginal gap required by McLean and von Fraunhofer.\(^{16}\)

These results were comparable to the in vitro study by Cetik et al,\(^{10}\) who compared the precision of zirconium oxide crowns based on conventional and digital (TRIOS) impressions. They did not find any significant differences in most measurement points between the restorations
obtained from the different impression modalities. Overall, all crowns were clinically acceptable and exhibited similar fit.

Measurements of the vertical marginal discrepancies showed that the smallest deviations of the crown copings were observed in group D (restoration fitted on the plaster cast), which is why this group ultimately performed best. The other three groups showed no significant differences. Overall, the restorations in group A (restoration fitted on the metal master model) showed the largest vertical discrepancies, which might have been due to the general inaccuracies in the conventional impression method or even due to impression errors.

Measurements of the horizontal marginal discrepancies showed that the crown copings in group C achieved the best values. In contrast, the other groups showed oversizing in the horizontal plane, which could be explained by an error in the impression-taking process.

The 3D measurements of the accuracy of fit showed that group D had the smallest marginal gap. The differences among the groups could be attributed to general impression errors.

When the present in vitro study results were compared to clinical examinations, the measured dimensions of the marginal fit increased significantly. It should be noted, however, that most previous studies evaluated the fit of ceramic copings; in contrast, the present study examined single crowns based on Co-Cr copings. The reasoning was that Co-Cr could avoid the sintering process used in ceramics. Thus, this study could focus purely on the accuracy of fit of the restorations resulting from the different impression processes. For example, a recent study by Berrendero et al. compared the accuracy of fit of all-ceramic crowns that were based on either a conventional silicone impression or an intraoral digital impression taken with the TRIOS scanner. They found a marginal gap of 106.6 μm with the digital method and a deviation of 119.9 μm with the conventional method. Comparable results were found in an in vivo study by Rödiger et al., who also investigated deviations of zirconium oxide crowns fabricated with CAD/CAM and the impression techniques mentioned above. They found marginal discrepancies of 151.68 μm in restorations made of impressions taken with the TRIOS scanner and 138.17 μm in restorations based on silicone impressions taken with the conventional method using the double-mix technique. The present results were better, potentially due to the fact that the sintering process used in making ceramics was avoided.

In addition, the in vivo study by Boeddinghaus et al. examined the marginal fit of zirconium oxide copings created with three different intraoral impression modalities and one conventional impression modality. Several intraoral scanners were used for the digital method, including the TRIOS scanner, which produced restorations with a marginal gap of 112 μm; the True Definition Scanner (3M), which produced restorations with a marginal gap of 88 μm from the zirconium oxide copings; and the CEREC Omnicam (Dentsply Sirona), which produced restorations with deviations of 149 μm. In contrast, the crowns created with the conventional method showed a gap of 113 μm, comparable to the result achieved with the TRIOS scanner.

The present study additionally performed 3D evaluations to examine the internal accuracy of the fit of the crown copings. The best internal fit, and thus the smallest internal gap, was achieved with the restorations in group D (87 μm), which employed the conventional impression on the metal master model. In comparison, groups A, B, and C showed deviations of 103, 105, and 109 μm, respectively. In contrast, Pradíes et al. performed a clinical study to compare the fit of ceramic crowns fabricated from conventional silicone impressions vs digital intraoral impressions. They found that restorations based on the digital method (149.86 μm) achieved better results than those based on the conventional method (165.77 μm). Similarly, an in vivo study by Zarauz et al. also found that the internal fit of all-ceramic crowns from the digital group (111.40 μm) performed significantly better than the crowns from the conventional group (173 μm).

In summary, the results presented in those studies were comparable to the results from in vivo studies, although study-related influencing parameters should also be considered. For example, the necessary sandblasting of the surfaces before the digitization process or the adhesive wax application to fix the crown copings could lead to minor measurement errors. Overall, the internal fit, like the marginal discrepancy, is an important criterion for the longevity of a dental restoration because it influences the fit of a dental restoration on the tooth die and thus the marginal fit.

Eames et al. showed that the application of a spacer on a tooth die provided additional space for material used in a subsequent cementation. That technique improved the fit of a crown and in addition increased the retention by 25%. That finding suggested that fixed dental restorations should generally have some space between the tooth and the restoration during the insertion process. The space should be a certain size, but not too generous, because this could lead to a disturbance in the bond and accelerate the wash-out of the cement. Furthermore, for restorations based on a certain material, such as ceramic, an oversized marginal gap could reduce the fracture resistance and the layer thickness of the restoration. In the literature, recommendations of a clinically acceptable marginal gap vary from 50 to a maximum of 120 μm.
With regard to future research, it would be interesting to investigate the precision of the different impression modalities on the basis of multi-unit restorations.29

CONCLUSIONS

From a clinical point of view, the results obtained in this study illustrated that all three impression modalities tested could be used as a basis for clinically satisfactory restorations. Based on the maximum marginal gap size of 120 μm, all restorations fabricated in this study were clinically acceptable. Therefore, digital impressions taken with an intraoral scanner could be regarded as an equivalent alternative to a conventional impression.

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