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ORIGINAL ARTICLE

Evaluation of intraoral digital impressions for obtaining gingival contour in the esthetic zone: accuracy outcomes

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Abstract

Objectives To assess the accuracy of intraoral digital impressions for gingival contour captured in the esthetic zone in vivo.

Material and methods Five participants with full upper dentition were recruited. For each participant, three scans were taken using two intraoral scanning (IOS) systems (3Shape TRIOS Color, TRC; CEREC Omnicam, OC) respectively; three conventional impressions (CIs) were taken using vinyl polysiloxane materials. The CIs of all participants were casted and then digitized with a model scanner (IScan D103i, Imetric). Precision was evaluated by superimposing three repeated STL datasets per participant within each group and calculating the (90th-10th)percentile/2 values. The CIs were the reference for evaluating the level of system error of the two IOS systems from the true value. Digital models from CI and each IOS group were superimposed and (mean positive deviation-mean negative deviation)/2[mean negative deviation, mean positive deviation] were calculated to assess trueness level of the two IOS systems.

Results For the soft tissue acquisition, precision results of each group were 45.10 ± 12.54 μm in TRC, 66.04 ± 13.46 μm in OC, and 63.66 ± 17.19 in CI (TRC vs OC, $p < 0.001$; TRC vs CI, $p = 0.001$; OC vs CI, $p = 0.66$). Trueness results were 80.12 ± 8.69[− 112.10 ± 9.88, 48.13 ± 13.79] μm in TRC and 82.70 ± 8.85[− 121.41 ± 15.40, 43.98 ± 11.86] μm ($p > 0.05$).

Conclusions In dentate situations, the two tested IOS systems achieved a clinically satisfying accuracy for capturing gingival contour in anterior maxilla, with a comparable or superior precision to the CI. TRC achieved a similar trueness and a higher precision level compared with OC.

Clinical relevance Intraoral digital impressions could be a recommended method for recording 3-dimensional gingival contour in the esthetic zone.

Keywords Digital impression · Intraoral scan · Accuracy · Soft tissue · Gingiva · Contour · STL

Introduction

Gingival contour alterations in the esthetic zone after a tooth extraction and implant placement create challenges for achieving pleasing esthetics. Soft tissue augmentation is widely used in a variety of clinical indications to compensate for hard and soft tissue remodeling following implant treatment, especially in the esthetic zone [1]. The practice of soft tissue measurement has gained increasing attention in the evaluation of treatment outcomes [2]. In contrast to extensive clinical application and timing of soft tissue management techniques, such as connective tissue graft [3, 4], available methods for accurately assessing outcome of gingival soft tissue change and these techniques remain limited [5]. Volumetric evaluation is indispensable when describing gingival contour alterations in an objective and comprehensive way. To date, the indirect digitization procedure is the most

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commonly used and validated method, in which both conventional impression and model scanning techniques are well established, to digitize the intraoral information in a non-invasive manner for volumetric evaluation of gingival contour alterations [6–12]. However, some drawbacks remain in the process: long process chain with potential sources of errors [13, 14], time-consuming, and patient discomfort when taking impressions [15, 16].

In contrast to the indirect digitization procedure, IOS transforms the intraoral surface information of the individual patient directly into 3D digital models, avoiding the long process chain and accumulated errors related to the conventional procedure [11, 13]. It is also proved to be time-efficient and patient-friendly [15, 16]. IOS have achieved a pronounced improvement in image quality, making it possible to document the soft tissue surface in terms of color and surface irregularity [17]. What's more, soft tissue is elastic and comparatively mobile compared with teeth. IOS capture of soft tissue in a contact-free manner [18] effectively eliminates the potential force to the soft tissue, which might be even advantageous when a post-operation immediate impression is required. Early attempts in using IOS to digitize the peri-implant soft tissue in esthetic zone [19–22] have been reported. However, little scientific evidence is available regarding the feasibility of IOS systems for obtaining gingival contour in the esthetic zone.

Up till now, to the best of our knowledge, there are no studies assessing the accuracy outcome of IOS for obtaining gingival contour in the esthetic zone. Therefore, the purpose of the present in vivo study is to (1) assess the accuracy of intraoral digital impressions for gingival contour in the esthetic zone, and thus, validate the feasibility of IOS for scanning gingival soft tissue and (2) compare the accuracy of the two tested IOS systems for gingiva contour capturing. The null hypotheses are: (1) the intraoral digital impressions exhibit similar precision as conventional impressions for obtaining the gingiva soft tissue and (2) the two intraoral digital impressions exhibit similar deviation from the conventional impression for obtaining the gingiva soft tissue.

Materials and methods

Participants recruitment

Five participants with full maxillary dentition were selected from a voluntary collective. All five volunteers signed the consent form and were recruited for the study.

Inclusion criteria:

- Good oral hygiene and periodontal conditions
- Adequate width of attached gingiva and height of papillae
- Complete maxillary dental arch except the missing third molar

Exclusion criteria:

- Obvious teeth mobility (mobility degree higher than I)
- Undergoing orthodontic treatment
- Obvious dentition malalignment (malalignment degree higher than I)
- With soft tissue lesions or deficiency in anterior maxilla

Intraoral scanning

Intraoral digital impressions were generated using CEREC Omnicam (OC, Sirona Dentsply, Germany; software version: SW 4.4.4) and 3Shape TRIOS Color (TRC, 3Shape, Denmark; software version: 2014-1) by an experienced operator. Scanning procedures were repeated 3 times with each system. Scan strategy: the scans always begin with the occlusal-palatal side of the first premolar in the first quadrant and turned to buccal side of the first premolar in the second quadrant, and then returned to the first quadrant [23, 24]. Part of alveolar mucosa was also scanned to ensure that the attached gingiva was fully captured. After frenum and alveolar mucosa were trimmed in the software manually, digital models were saved and exported in STL file format. The main parameters of the two IOS systems are listed in Table 1 [25].

Conventional impressions

For each participant, three upper jaw impressions were made using full-arch metal stock impression trays with vinyl polysiloxane material (Silagum MixStar Putty Soft, DMG, Hamburg, Germany). All conventional impressions (CIs) were made following the manufacturer's instruction under the same conditions (in the same room with a controlled temperature 23 ± 2 °C, relative humidity of 45%, and air pressure of 760 ± 5 mmHg) by the same experienced dentist . All impressions were stored for 8 h at ambient room temperature and then poured with type IV dental stone (Die-stone, Heraeus Kulzer, South Bend, USA) by the same technician. Impression trays were removed from the stone models after 40 min.

Each participant received intraoral scan and conventional impression taking. The intraoral scan was prior to the conventional impression procedure. The sequence of the two IOS systems was randomly determined. All the impressions were taken in a single appointment.

Digitization of the stone casts

The models were stored at room temperature (23 °C) and ambient humidity for 72 h and then scanned with a high-resolution extraoral scanner at 6-μm precision (IScan

Table 1 The two intraoral scanning systems used in this study

	CEREC Omnicam	3Shape TRIOS Color
Powder	No	No
Color	Yes	Yes
Scanner size(L × W × H)	228 × 16 × 16 mm	320 × 56 × 16 mm
Data capture mode	Video sequence	Video sequence
Data capture principle	Triangulation	Confocal microscopy
Digital workflow	Data transfer via cloud-based platform CEREC connect;closed system	Data transfer via cloud-based platform 3Shape TRIOS inbox;closed system

D103i, Imetric, Courgenay, Switzerland; software version: IScan 3D exocad 8.1) as described in previous publications [26, 27]. The STL files were exported.

The terms "trueness" and "precision" represent different measures of accuracy [26]. Trueness is defined as the comparison between a reference dataset and a test dataset. The measured deviations between the reference dataset and the test dataset determine the accuracy of a scanner. Precision is defined as a comparison between different datasets obtained using the same digital scanner. Such an examination provides information about the reproducibility of a scanner.

Assessment of IOS and CI precision for gingival soft tissue

Digital models from repeated scans were compared with assess precision. With three repeated impressions per participant in every group, three superimpositions were made via the best-fit algorithm in the dedicated software (Geomagic Qualify 2014, Geomagic, USA). Next, the models were trimmed to the soft tissue contour, including the labial aspect of attached gingiva, papillae, and about 0.5 mm of tooth surface below gingival margin. The trimmed models were 3D compared for deviation assessment. A color-coded 3D deviation map of each superimposition was displayed as a screenshot for visual analysis. Depending on the STL resolution of the digital models, each trimmed model consisted of 8000–16000 triangle surfaces. As for the two aligned models, the software calculates the distance from each STL vertex point of triangle surface in the test model to the nearest vertex point in the reference model. The distance datasets were saved as CSV files and imported into SPSS (IBM SPSS Statistics 23.0, NY, USA) software. The raw datasets were sorted into ascending order. The 10th and 90th percentiles of the distance values were calculated as a measure for the deviation between two aligned models. The highest 10% and lowest 10% of values were ignored. The precision in each group was measured by calculating the (90th-10th)percentile/2 values. This meant that 80% of the model differences were located within it [24, 28–30].

Assessment of IOS trueness for gingival soft tissue

For each participant, deviation between one IOS model and each of the three CI models was calculated, respectively, and the mean value of the three deviation results was used to assess trueness (Fig 1). The alignment and trimming methods were the same as above methods. After 3D comparison of the two aligned models, a color-coded 3D deviation map of each superimposition was also displayed as a screenshot for visual analysis. The measured deviation is negative if the surface of the IOS model is inside the surface of the CI model and positive if it is outside. Mean negative deviation as well as mean positive deviation was exported and mean positive deviation--mean negative deviation)/2was calculated subsequently [13, 31]. Trueness was thus assessed by (mean positive deviation--mean negative deviation)/2[mean negative deviation, mean positive deviation].

Assessment of IOS and CI precision for teeth

In each group, three repeated digital models were superimposed. Next, the superimposed models were trimmed to the teeth and precision was subsequently assessed via the aforementioned alignment and surface comparison method (the (90^{th}-10^{th})percentile/2).

Assessment of IOS trueness for teeth

Each of the three CI models was also used as a reference to assess the trueness of IOS for the teeth. The aforementioned alignment and surface comparison method ((mean positive deviation-mean negative deviation)/2[mean negative deviation, mean positive deviation]) was used to assess the IOS trueness for teeth.

Statistical analysis

The normal distribution of the fifteen mean negative deviation, mean positive deviation, (mean positive deviation-mean negative deviation)/2 and (90th-10th)percentile/2 values

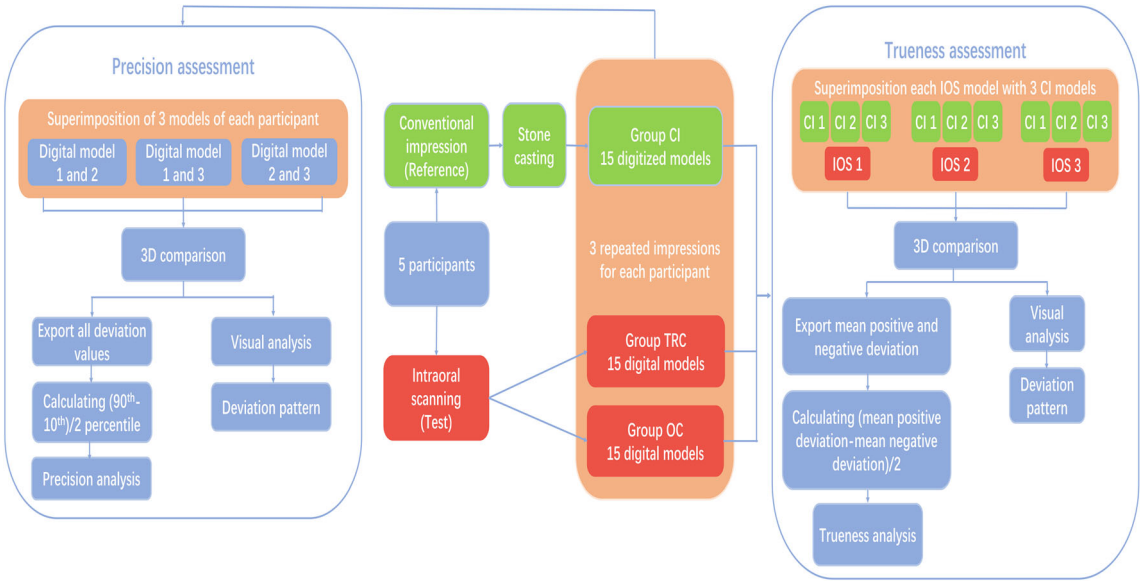

Fig. 1 Study workflow of the gingival contour datasets obtaining and analysis

within each group was determined using the Kolmogorov–Smirnoff test. The mean, media, standard deviation, 95% confidence interval, maximum, and minimum were calculated. For trueness assessment, statistical differences between groups were analyzed via independent-samples t test (α = 0.05). For precision assessment, Levene's test was used to assess the equality of variances for all groups ($p < 0.1$), and statistical differences among groups were analyzed via one-way ANOVA (α = 0.05). To compare the accuracy results of the soft tissue and the teeth for each group, independent-samples t test (α = 0.05) were used. The workflow of the gingival soft tissue datasets obtaining and analysis were shown in Fig 1.

Results

The Kolmogorov–Smirnoff test revealed a normal distribution for the mean negative deviation, mean positive deviation, (mean positive deviation-mean negative deviation)/2 and (90^{th}-10^{th})percentile/2 in all groups. Leven's test indicated an equality of variances ($p > 0.1$). Therefore, the precision results of each group could be compared pairwise using post hoc LSD test.

Precision results of IOS and CI for the soft tissue

For 3D comparison of gingival tissue within group IOS and CI, it showed a precision level of 45.10 ± 12.54 μm for group TRC, 66.04 ± 13.46 μm for group OC and 63.66 ± 17.19 μm for group CI (Table 2, Fig. 4). A statistically significant difference was found among three groups ($p < 0.001$). The post hoc LSD test showed a statistically significant difference between group TRC and group CI ($p = 0.001$), as well as group TRC and group OC ($p < 0.001$), while no statistically significant difference was found between group OC and group CI ($p = 0.66$). Positive and negative deviations were occurring irregularly in 3D deviation distributions maps of precision outcomes (Fig. 2).

Trueness results of IOS for the soft tissue

For 3D comparison of gingival tissue between group TRC and CI, it showed a trueness level of 80.12 ± 8.69[− 112.10 ± 9.88, 48.13 ± 13.79] μm. For 3D comparison of gingival tissue between group OC and CI, it showed a trueness level of 82.70 ± 8.85[− 121.41 ± 15.40, 43.98 ± 11.86] μm (Table 3, Fig. 5). No statistically significant difference was found in the mean negative deviation ($p = 0.060$), mean positive deviation ($p = 0.39$), and (mean positive deviation-mean negative

Table 2 Precision results (mean ± SD, median, 95% confidence interval, minimum, maximum values, μm) of group TRC, OC, and CI for soft tissue

	Mean ± SD	Median	95% confidence interval	Maximum	Minimum (μm)
TRC	45.10 ± 12.54	39.05	38.15–52.04	77.20	29.65
OC	66.04 ± 13.46	65.32	58.58–73.49	91.75	49.10
CI	63.66 ± 17.19	59.95	54.14–73.17	104.45	42.40

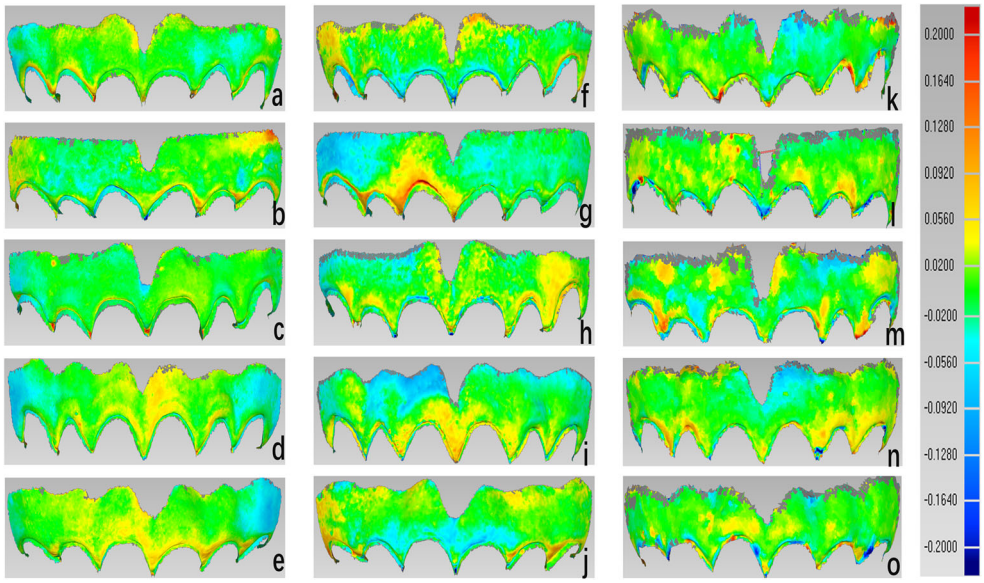

Fig. 2 Typical deviation distributions within each group. **a**–**e** showed the typical deviation distributions in TRC. **f**–**j** showed the typical deviation distributions in OC. **k**–**o** showed the typical deviation distribution in CI

deviation)/2 ($p = 0.43$). 3D deviation distribution of trueness outcomes is shown in Fig. 3. Larger deviation was seen in the distal area, as well as free gingiva and papilla areas.

In general, most of the (mean positive deviation-mean negative deviation)/2 and (90^{th}-10^{th})percentile/2 values did not exceed 100 μm.

Precision results of IOS and CI for the teeth

For 3D comparison of the teeth within group IOS and CI, it showed a precision level of 30.42 ± 11.14 μm for group TRC, 38.63 ± 7.48 μm for group OC, and 23.71 ± 5.94 μm for group CI (Table 4, Fig. 4). When comparing the precision results of the soft tissue with that of the teeth, a statistically significant difference was found in group TRC ($p < 0.001$), group OC ($p < 0.001$), and group CI ($p < 0.001$).

Trueness results of IOS for the teeth

For 3D comparison of teeth between group TRC and CI, it showed a trueness level of 37.61 ± 3.53[− 46.78 ± 3.40, 28.44 ± 4.78] μm. For 3D comparison of teeth between group OC and CI, it showed a trueness level of 49.81 ± 4.84[− 59.63 ± 6.51, 39.99 ± 5.08] μm (Table 5, Fig. 5). When comparing the trueness results of the soft tissue with that of the teeth, a statistically significant difference was found both in group TRC ($p < 0.001$) and OC ($p < 0.001$).

Discussion

Unlike teeth and rigid structures, the characteristics of soft tissue are difficult to imitate by artificial materials in vitro. Thus, an in vivo study is essential to investigate the clinical situation of intraoral digital impressions for soft tissue. Since the real dimension of the gingiva is difficult to measure in vivo, the present study used the conventional impression, the proven and most commonly used method, as a reference to assess the trueness of intraoral digital impressions. To the best of author's knowledge, this is the first study that focuses on the accuracy of intraoral digital impressions for gingival contour acquisition. The first null hypothesis was partly rejected. The intraoral digital impressions exhibited comparable or superior precision to the conventional impression for obtaining gingiva soft tissue in anterior maxilla. The second null hypothesis was accepted. The two intraoral digital impression

Table 3 Trueness results (mean ± SD, median, 95% confidence interval, minimum, maximum values, μm) of two IOS groups for soft tissue

	Mean ± SD	Median	95% confidence interval	Maximum	Minimum (μm)
TRC*	80.12 ± 8.69 [− 112.10 ± 9.88, 48.13 ± 13.79]	82.02 [− 115.90, 50.10]	75.31–84.93 [− 117.57 − (− 106.63), 40.49–55.77]	91.05 [− 94.90, 72.30]	62.85 [− 127.90, 27.60]
OC*	82.70 ± 8.85 [− 121.41 ± 15.40, 43.98 ± 11.86]	82.15 [− 120.21, 44.10]	77.80–87.60 [− 129.94 − (− 112.89), 37.42–50.56]	103.34 [− 87.30, 64.70]	68.30 [− 153.80, 26.70]

*(mean positive deviation-mean negative deviation)/2[mean negative deviation, mean positive deviation]

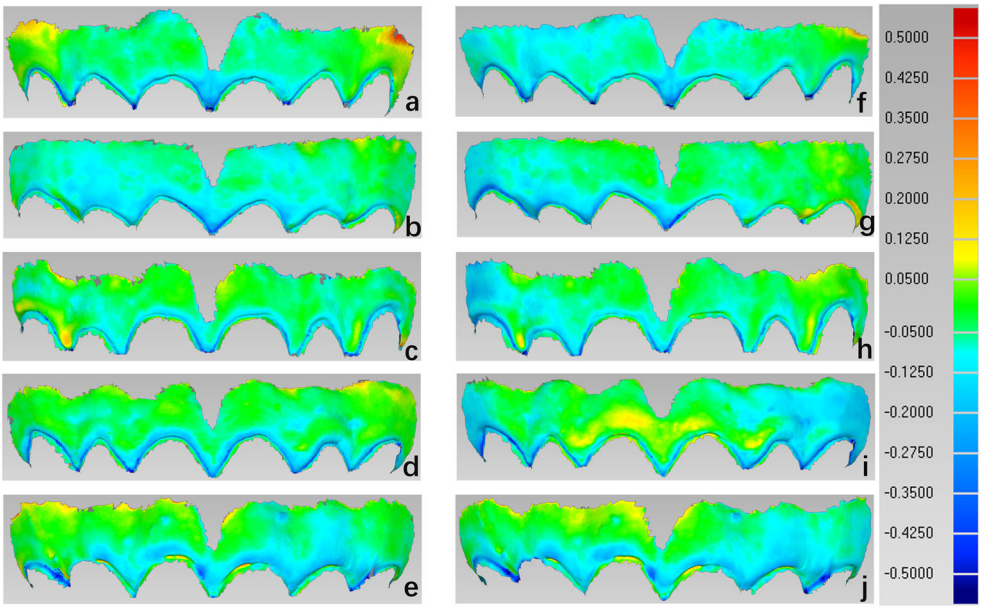

Fig. 3 Typical deviation distributions between IOS groups and CIs. **a**–**e** showed the typical deviation distributions between TRC and CIs. **f**–**j** showed the typical deviation distributions between OC and CIs.

exhibited comparable deviation from the conventional impression. The results of this study indicate that intraoral digital impressions have a clinically acceptable level of accuracy and may become a viable method to record 3D gingival contour in a relatively short dental arch.

Digital scanning and dedicated software for superimposition of the resultant STL datasets represent an efficient technique to measure and compare the accuracy [32, 33]. The accuracy outcomes may be affected by the digital scanner, the choice of digitization method, the alignment methodology, as well as the distribution and number of surface data points [31]. The superimposition of two digital models was performed employing a "best-fit alignment" due to the lack of reference shapes [13].

Adequate methods of interpretation of the divergences after superimposition should be used to receive values for trueness and precision. Since trueness and precision are defined as two independent and complementary aspects to evaluate accuracy in digital technology, we choose to use the mean positive deviation and mean negative deviation for trueness assessment and the (90th-10th) percentile/2 including 80% model deviations for precision assessment. These two parameters were commonly used in previous studies [13, 24, 28–31].

From the precision results of the soft tissue acquisition, the conventional impression showed less optimal precision, especially in marginal gingiva and papillae region. The following factors may contribute to the results: firstly, during conventional impression procedure, impression compression inevitably causes local deformation of the soft tissue, especially when the impression was removed from the jaw. Gingival margin and papillae region are more sensitive to this kind of force than attached gingiva and therefore varied between repeated impressions. Furthermore, the deformed soft tissue was not able to recover in a short period since its viscoelasticity. Hence, the intraoral scan was prior to the conventional impression taking. Secondly, impression material tearing is often seen in interdental papillae when separating impression from cast stone. In addition, small debris and air bubbles are difficult to be entirely avoided. Since intraoral scan has no contact with soft tissue and captures directly, all the abovementioned limitations are thus avoided.

Trueness of palatal soft tissue scanning was reported in two recent in vivo studies by Gan et, al. [34] and Deferm et, al [17]., which are the only two studies on soft tissue scanning in vivo, to the best of our knowledge. In their studies, conventional impressions were directly used as the gold standard to evaluate the trueness of an intraoral digital impression. However, precision of the conventional impression was not assessed. According to the precision results in our study, the conventional models are less precise as a "gold reference" to assess the trueness results of the intraoral scanning systems for soft tissue. Therefore, it is more reasonable to use three

Table 4 Precision results (mean ± SD, median, 95% confidence interval, minimum, maximum values, μm) of group TRC, OC, and CI for teeth

	Mean ± SD	Median	95% confidence interval	Maximum	Minimum (μm)
TRC	30.42 ± 11.14	29.35	24.25–36.59	53.89	16.65
OC	38.63 ± 7.48	37.96	34.38–42.88	53.04	27.86
CI	23.71 ± 5.94	24.35	20.43–27.00	33.91	15.62

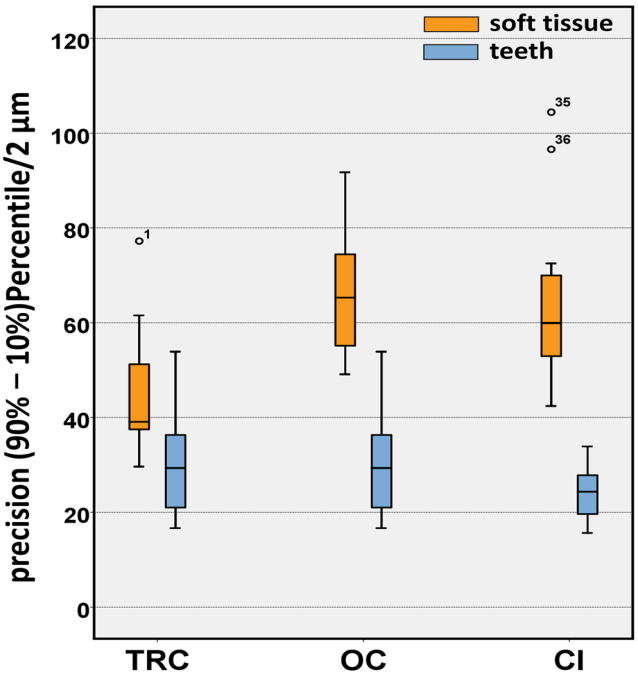

Fig. 4 Precision results of the soft tissue and hard tissue in all groups. The box represents the range of 50% of the difference measurements. The bar within the box represents the mean value. Circles represent outlier difference measurements (more than 1.5 times away from box width)

repeated conventional impressions as comparison, instead of single conventional impression.

From the visual analysis of trueness results, the larger deviation in the distal areas can be explained mainly by the registration errors in IOS procedure. Registration errors caused larger deviations with the extending of scan areas. Error propagation leads to increased deformation toward the distal end of the dental arch [33, 35]. This source of errors does not exist in conventional impressions. Interestingly, we also found that the IOS model were "below" the CI model in free gingiva and papilla areas for each superimposition. The possible explanation was that the impression materials inevitably flowed into the gingival sulcus, causing the displacement of free gingiva, which was like a gingival retraction to some degree. Thus, from the technical point of view, although the conventional impression procedure is commonly used and proven, it has obvious limitations to record the sensitive soft tissue, especially in free gingiva and papilla areas. In addition, factors such as limited suitability for storage, deficient dimensional stability, disinfection in antiseptic solution, transport into the dental laboratory at different climatic conditions, and the overall long process chain with accumulative errors may also lead to more deviations from the real dimension. Therefore, it still remains unclear which results, IOS or CI, are closer to the true value since the real dimension of the soft tissue is unable to measure in vivo. The trueness results in our study need to be carefully understood.

For palatal soft tissue scan, Gan et al. reported a trueness level of 130.54 ± 33.95 μm and a precision level of 55.26 ± 11.21 μm, while Deferm et al. reported a trueness level of 0.02 ± 0.07 mm and a precision level of 80 μm. Compared with the results of the two studies, the present study reports higher results of both precision and trueness on the gingival soft tissue. This is probably attributed to an obviously smaller scan range in our study. In the IOS process, stitching and registration of a neighboring single image are made based on reference points in the overlapped area [35]. If the adjacent surfaces are stable and show enough reference points, it is easy to match the overlapped area, leading to reliable scanning results. Teeth vary more in shape and height than soft tissue, which contributes to the majority of the reference points in registration. When scanning gingival contour in anterior maxillary region, intraoral cameras were able to capture both the teeth and the majority of the soft tissue in a single image, thus minimizing the registration error in a more optimal range.

In the present study, in order to better interpret the results for soft tissue acquisition, the precision results of both digital and conventional impressions for teeth were served as a contrast, though dentition results have been reported by several previous studies [32, 33]. In Ender et al's studies, 3Shape TRIOS Color and CEREC Omnicam showed a mean precision of 26.1 ± 3.8 μm and 37.4 ± 8.1 μm for quadrant dental impression [32]. The present study used the same surface comparison method to evaluate the precision of IOS and showed similar but slightly lower precision for teeth acquisition (30.42 ± 11.14 μm for 3Shape TRIOS Color and 38.63 ± 7.48 μm for CEREC Omnicam). The probable explanation is that the anterior region has less geometric information compared with the posterior region, leading to a relatively high registration error [33]. In addition, we noticed that the conventional impression showed high precision for teeth whereas obviously lower precision for soft tissue (23.71 ± 5.94 μm vs 63.66 ± 17.19 μm, $p < 0.001$). Therefore, it seems that

Table 5 Trueness results (mean ± SD, median, 95% confidence interval, minimum, maximum values, μm) of two IOS groups for teeth

	Mean ± SD	Median	95% confidence interval	Maximum	Minimum (μm)
TRC*	37.61 ± 3.53 [− 46.78 ± 3.40, 28.44 ± 4.78]	38.70 [− 47.40, 29.10]	35.65–39.57 [− 48.66 − (− 44.90), 25.79–31.09]	32.10 [− 41.03, 35.60]	41.50 [− 52.60, 19.10]
OC*	49.81 ± 4.84 [− 59.63 ± 6.51, 39.99 ± 5.08]	50.90 [− 59.90, 39.90]	47.13–52.50 [− 63.24 − (− 56.03), 37.18–42.81]	39.70 [− 44.09, 49.40]	58.20 [− 69.20, 33.20]

*(mean positive deviation-mean negative deviation)/2[mean negative deviation, mean positive deviation]

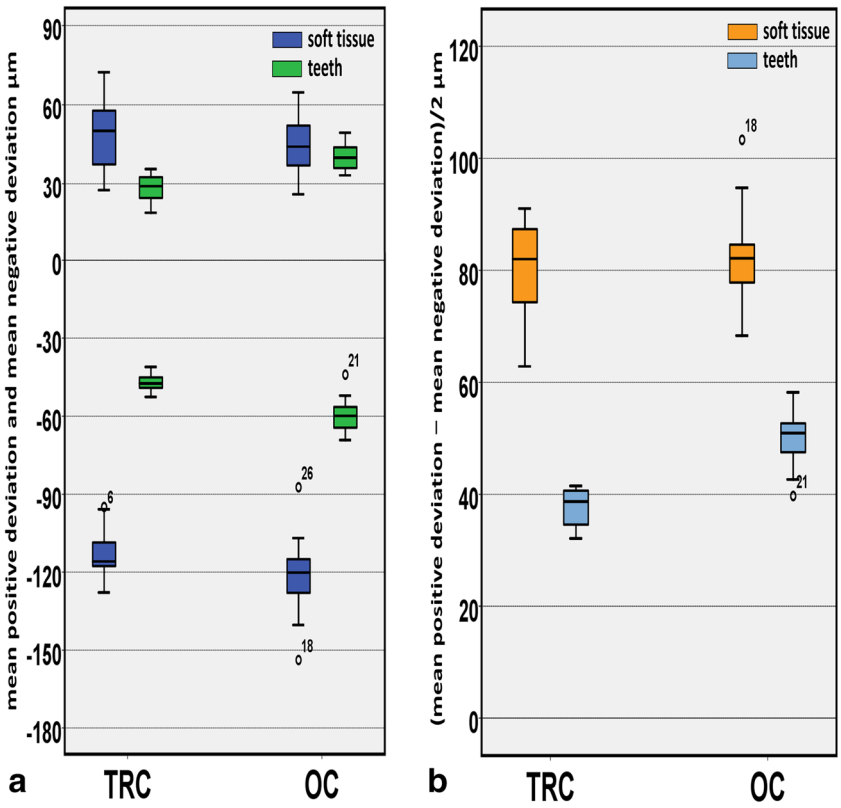

Fig. 5 The mean positive deviation and mean negative deviation of the soft tissue and hard tissue (**a**) and the (mean positive deviation-mean negative deviation)/2 results (**b**) in the two IOS groups. The box represents the range of 50% of the difference measurements. The bar within the box represents the mean value. Circles represent outlier difference measurements (more than 1.5 times away from box width)

intraoral scanning may be a superior alternative to conventional impression for the acquisition of soft tissue information in a relatively short dental arch.

In dentate situations, although soft tissue scanning showed less accuracy than teeth scanning, it was sufficient as a reference though, for the technician to build an ideal emergence profile for restorations. Moreover, the accuracy of intraoral gingival scanning in soft tissue is adequate, if not excessive, for the documentation of gingival contour in various clinical scenarios and subsequent gingival volumetric evaluation which, after all, requires less accuracy than implant-abutment connection (or fixed partial denture) in a clinical perspective.

However, it is necessary to emphasize that for edentulous or partial edentulous patients, it is not recommended to utilize intraoral digital impressions for soft tissue contour acquisition due to the lack of anatomic landmarks [36, 37]. To date, conventional impressions and subsequent model scanning are still recommended for obtaining 3D datasets in edentulous or partial edentulous patients. Additionally, mucosa and frenum can be hardly reproduced precisely by either intraoral digital impressions or conventional impressions. Intraoral digital impressions are gaining increasing popularity and showing good potential. In clinical practice, utilization of IOS systems may present advantages specific to the recording of soft tissue. However, the limitations of the study should be addressed. We should be cautious to interpret the results of the present study, since different intraoral scanning systems, conventional impression materials, even different surface comparison algorithms might influence the accuracy results, given the large heterogeneity that was found between the available studies. Additionally, the number of subjects in each group was comparably low from a clinical point of view. Further studies with larger subject sample size are necessary.

Conclusions

In dentate situations, the two tested IOS systems achieved a clinically satisfying accuracy for capturing gingival contour in anterior maxilla, with a comparable or superior precision to the conventional impression. Intraoral digital impressions could be a recommended method to record 3-dimensional gingival contour in the esthetic zone. 3Shape TRIOS Color achieved a similar trueness and a higher precision level compared with CEREC Omnicam.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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