Establishment and evaluation of a three-dimensional quantitative analysis method of dental plaque based on intraoral scanner technique

Abstract:

Purpose： Quantitative evaluation of dental plaque is necessary for both clinical and scientific work. This study aimed to examine the reliability of this 3D image analysis method by digitally analyzing the color 3D images obtained from an intraoral scanner, and then detecting and quantifying the plaque information and comparing it with the clinical examination results.

Materials and methods: A total of 140 teeth from 5 subjects with a standard dentition were enrolled in this study, and plaque examination was performed at two different stages: after 24 hours without oral hygiene (T1) and after habitual brushing (T2). At each time point, a clinical examination was performed and the Quigley-Hein plaque index of each tooth surface was recorded separately, followed by the use of an intraoral scanner to obtain color 3D images, which were analyzed and calculated using Geomagic Wrap 2021.

Results: It was found that the percentage of plaque staining area calculated from the 3D image analysis correlated well with the plaque index recorded during the clinical examination: the Spearman correlation coefficient at T1 was 0.9136 ($P<0.001$) for all tooth surfaces, 0.7849 and 0.9217 ($P<0.001$) for the vestibular and lingual surfaces, respectively; at T2 the Spearman correlation coefficient was 0.9061 ($P<0.001$) for all tooth surfaces, and 0.8579 and 0.9001 ($P<0.001$) for vestibular and lingual surfaces, respectively. The measurements of the three investigators were in good agreement, with intraclass correlation coefficients of 0.989 and 0.992 ($P<0.001$) for the vestibular and lingual surfaces at T1, and 0.964 and 0.983 ($P<0.001$) for the vestibular and lingual surfaces at T2.

Conclusion: The 3D image analysis technique used in this study provides a basis for more accurate clinical quantification of dental plaque, initially establishing a digital 3D evaluation system of dental plaque suitable for use in research and clinical practice.

Keywords: dental plaque, intraoral scanner, 3D image processing, plaque index

1. Introduction

Dental plaque bacteria and their products are important initiators of caries and periodontal diseases [1], and effective plaque control is a key measure to prevent common oral diseases. Therefore, how to evaluate dental plaque quantitatively is necessary for both clinical and research work. The commonly used clinical method of plaque evaluation is mainly based on visual observation to determine the plaque accumulation area [2-3], which is highly subjective and dependent on the personal experience and level of the researcher and is also not conducive to data retention.

With the increasingly widespread application of computers in the medical field, digital technology plays an important role in both the recording and analysis of 2D images in the clinic as well as the design and reconstruction of 3D forms [4-6], enabling more efficient and standardized completion of related clinical support work, while allowing for the perfect preservation of medical records.

In recent years, image analysis has been gradually used for the quantitative evaluation of dental plaque. In 2D image analysis, intraoral photographs are taken with an extraoral camera, and the plaque information is quantified on the basis of 2D images by detecting the plaque on fluorescent images [7-9] or stained plaque on conventional images [10]. However, due to the limitations of the technique, 2D image analysis can only be used in the anterior region where photographs can be easily taken, and it is necessary to avoid crowding, twisting, and displacement of individual teeth. Even so, due to the curvature of the dentition itself, the 3D information is inevitably slightly obscured and distorted during the recording of the 2D images, and the results of the subsequent analysis of the 2D images are not always consistent with the actual 3D dentition.

Intraoral scanners, as emerging digital devices in recent years, have been widely used in the field of dental clinical and scientific research [11-13]. Intraoral scanners are capable of creating color 3D images directly in a short period of time, including information on each tooth surface of the complete dentition, which can be a beneficial tool for detecting dental plaque levels [14]. Chen et al. used the 2D pictures of dental plaque to match the 3D dental models in their study to simulate the plaque distribution reflecting the 3D morphology [15]. Giese-Kraft et al. used 3D images obtained from an intraoral scanner to assist in the observation of plaque distribution information, using the RMNPI (the Rustogi et al modified Navy plaque index) as a record, and the results showed that the 3D images were highly reliable for detecting the plaque information [16].

However, in the current study, the evaluation of dental plaque by intraoral scanners is still limited to recorded data and observations, and the advantages of digitalization have not been fully utilized to quantify the dental plaque level. Therefore, this study aimed to investigate the reliability of this 3D image analysis method by digitally analyzing the 3D images obtained from the intraoral scanner and then detecting and quantifying plaque information and comparing it with clinical examination results.

2. Materials and Methods

2.1 Study design and participants

The study was a non-randomized, non-blinded, self-controlled trial with a single tooth as the subject. Volunteers were recruited from the prosthodontic students of Shanxi Medical University.

The inclusion criteria were permanent dentition, complete dentition, no restorations, no significant dental defects, no significant gingival hyperplasia or recession, no obvious periodontal inflammation, and in good general condition. The exclusion criteria were non-permanent dentition, edentulous teeth, missing teeth, severe dental defects, severe periodontitis, severe systemic diseases, and patients who refused to undergo the experiment. The total number of participants was 5, including 2 males and 3 females, with an average age of 26 years old; each with a standard dentition of 28 teeth and altogether 140 teeth.

2.2 Comparison of 3D image analysis method and clinical examination results

In order to detect different levels of dental plaque, each participant will receive twice plaque recording and evaluation, including plaque levels after 24 hours without oral hygiene (T1) and plaque levels after habitual brushing (T2). Participants refrained from oral hygiene (including teeth brushing, using various cleaning aids such as flossing or flosser) for 24 hours before the start of the experiment. Plaque staining was performed by the investigator on their entire dentition: a cotton swab saturated with plaque indicator solution (C.I. Medical, Japan) was pressed gently on the gingival papillae of all teeth to spread the indicator solution to the tooth surface, and then the mouth was rinsed twice to remove the excessive staining solution. The Quigley-Hein plaque index (Turesky modified Quigley-Hein PI) on the vestibular and lingual surfaces of all teeth of the participants was recorded by the same investigator. After completing the clinical examination, the full intraoral dental information was scanned using an intraoral scanner (3shape, Danmark) to obtain color 3D image data. Next, participants will choose their preferred oral cleaning tool, including a manual toothbrush (Colgate Ultrasoft, America) or an electric toothbrush (Philips Sonicare HX6511/50, Holland), along with a toothpaste provided by the laboratory (MaxFresh, America), the participants brushed their teeth in the same way and at the same time as they usually do. After completion of habitual brushing, the participants were stained again for dental plaque, and clinical examinations and intraoral scans were performed to obtain the plaque index and 3D images.

The scanned 3D images were separated for each tooth individually by another investigator using the curve tool in Geomagic Wrap 2021 to determine the borders of the vestibular and lingual surfaces of each tooth and to depict the borders of plaque staining based on the staining information. The area of each tooth surface was calculated separately as well as the area of plaque staining, as shown in Figure 1, and then the percentage of plaque staining area for each tooth surface was derived and tested for correlation with the corresponding plaque index of each tooth surface in the clinical examination. Figure 2 shows the different dental plaque levels recorded at T1 and T2.

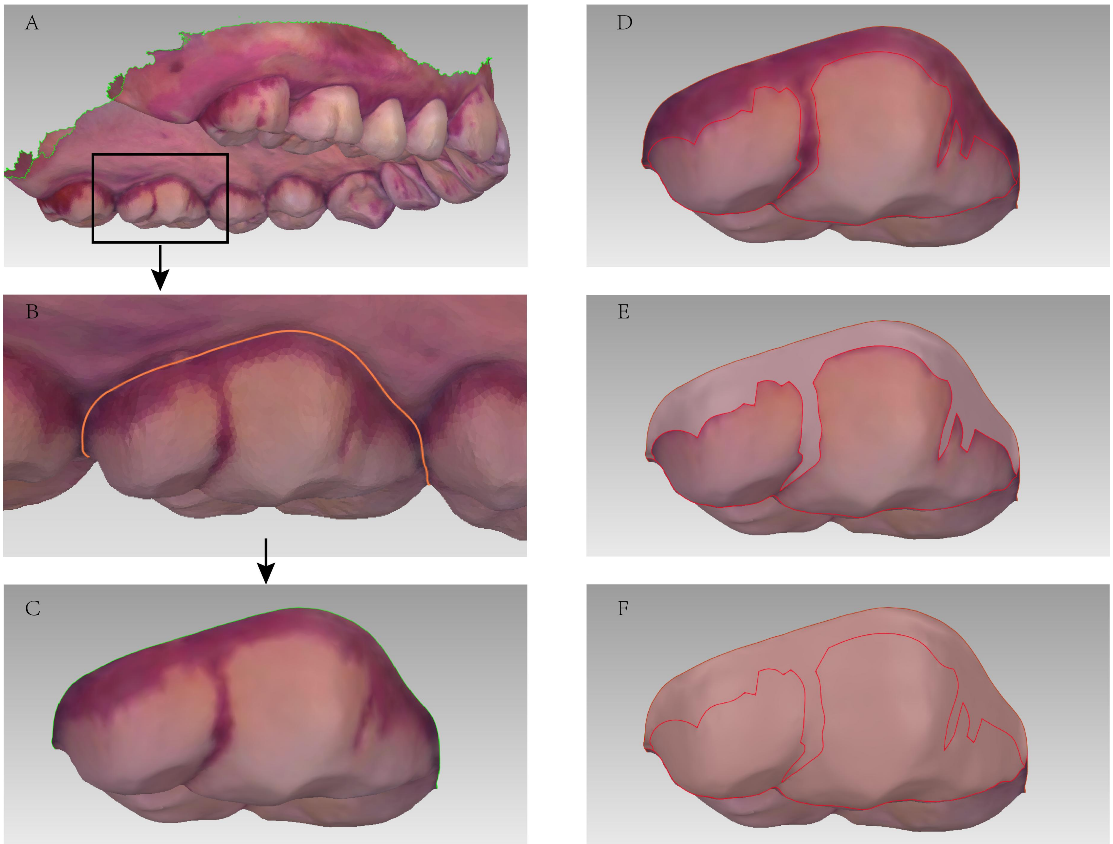

Figure 1: 3D image analysis process.

A: Color 3D image data obtained by intraoral scanner.

B: Frame the tooth 26.

C: Separate 26 individually.

D: 26 lingual surface boundary and lingual plaque staining boundary.

E: Calculate the area of 26 lingual plaque staining.

F: Calculate the overall area of 26 lingual surface.

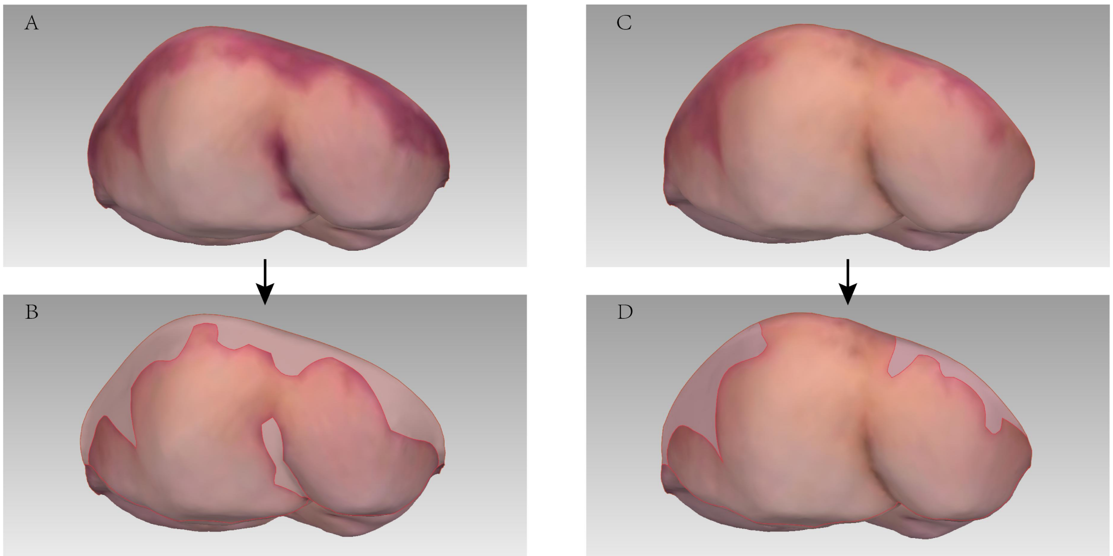

Figure 2: 3D images of different plaque levels at T1 and T2
A, B: 16 plaque levels on the lingual surface after 24 hours without oral hygiene (T1)
C, D: 16 plaque levels on the lingual surface after habitual brushing (T2)

2.3 Reproducibility test of the 3D image analysis method

The 3D images obtained from the intraoral scanner were processed again by two other investigators using Geomagic Wrap 2021 to determine the borders of each tooth surface and the plaque staining areas, and to calculate the percentage of plaque staining on the corresponding tooth surfaces to evaluate the reproducibility of the technique.

2.4 Statistics

SPSS 26.0 statistical software was applied for analysis. The data of clinical plaque index and 3D image analysis calculations for different dental plaque levels at T1 and T2 were recorded separately, and divided into vestibular and lingual surfaces. The correlation between the data calculated by the 3D image analysis and the corresponding plaque index of clinical examination was analyzed by nonparametric correlation analysis and expressed by the Spearman correlation coefficient; the reproducibility test of the image analysis method was performed by the consistency test of continuous variables and expressed by the Intraclass Correlation Coefficient (ICC).

3. Results

3.1 Comparison of 3D image analysis method and clinical examination results

The 3D information of the participants' dentition after plaque staining was recorded by the intraoral scanner at T1 and T2, and divided into vestibular and lingual surfaces for image analysis to calculate the percentage of plaque staining area, and the non-parametric correlation analysis was performed with the corresponding dental plaque index recorded by clinical examination, which showed a high correlation agreement between the two at different plaque levels and on different dental surfaces. As shown in Figure 3, the Spearman correlation coefficient was 0.9136 ($P<0.001$) for all dental surfaces at the moment of T1, with 0.7849 ($P<0.001$) for the vestibular surface and 0.9217 ($P<0.001$)

for the lingual surface; at the moment of T2, the Spearman correlation coefficient was 0.9061 (P<0.001) for all dental surfaces, with 0.8579 (P<0.001) for the vestibular surface and 0.9001 (P<0.001)for the lingual surface.

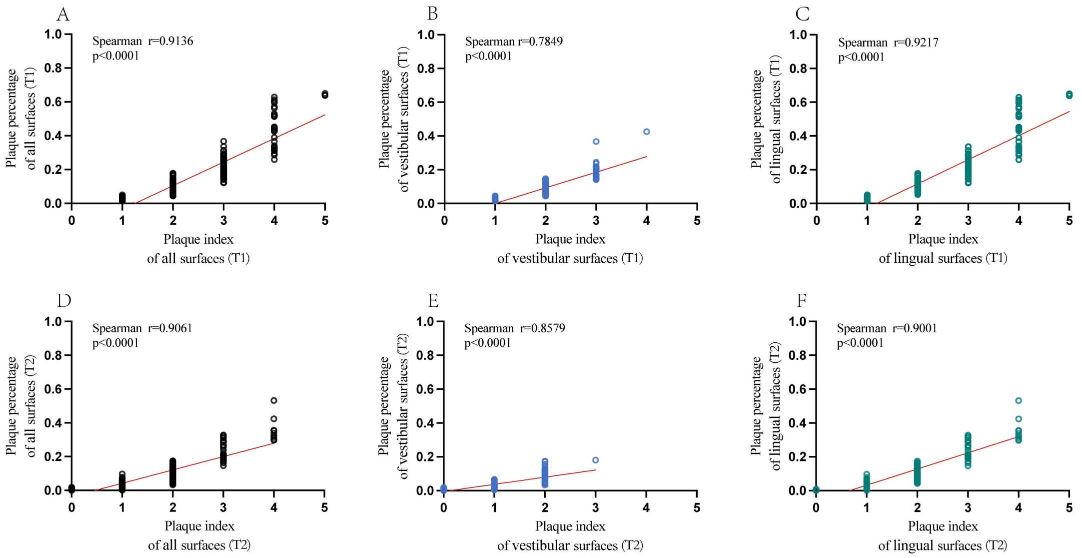

Figure 3: Comparison of the results of 3D image analysis method and clinical examination.
A: Comparison of all dental surfaces results at T1, Spearman r=0.9136 (p<0.0001).
B: Comparison of vestibular surface results at T1, Spearman r=0.7849 (p<0.0001)
C: Comparison of lingual surface results at T1, Spearman r=0.9217 (p<0.0001)
D: Comparison of all dental surfaces results at T2, Spearman r=0.9061 (p<0.0001).
E: Comparison of vestibular surface results at T2, Spearman r=0.8579 (p<0.0001)
F: Comparison of lingual surface results at T2, Spearman r=0.9001 (p<0.0001)

3.2 Reproducibility test

Two other investigators analyzed the 3D plaque information again using the same method with Geomagic Wrap 2021 and calculated the corresponding percentage of plaque staining area, and the obtained data were tested for consistency. The results showed that at the moment of T1, the ICC values were 0.989 and 0.992 (p<0.001) for the vestibular and lingual surfaces, respectively; while at the moment of T2, the ICC values were 0.964 and 0.983 (p<0.001) for the vestibular and lingual surfaces, respectively. It can be concluded that there is a good agreement between the results measured by the three investigators.

4. Discussion

In recent years, image analysis methods have been gradually used for the quantitative evaluation of dental plaque. The 2D image analysis method cannot completely detect the plaque information of the whole dentition due to the limitation of its photographing approach [7-10]. Intraoral scanners can be a favorable tool for the 3D detection of dental plaque due to their convenient and efficient acquisition of 3D dental information [14-16]. However, in the current study, the 3D images obtained from the scanners were limited to observation and recording, without combining the advantages of digitalization for an in-depth analysis of the obtained images. Therefore, this study aimed to construct a more accurate and comprehensive 3D dental plaque evaluation method by quantitatively analyzing the 3D images obtained from intraoral scanners based on digital technology.

In this study, the 3D images were obtained using an intraoral scanner, and they were not directly used to observe the staining plaque information. Instead, the 3D images were digitized by Geomagic Wrap 2021 software to depict the boundaries of each tooth surface and the corresponding plaque area, and then the surfaces were boxed for area calculation, and the plaque was quantitatively evaluated by the percentage of plaque to the tooth surface area. In this study, the area of the boxed surfaces was calculated as 3D information, which is more suitable for the actual situation than the previous studies in which 2D images were processed. At the same time, the intraoral scanner can also easily obtain information in the posterior teeth and other areas that are not easily photographed, which is conducive to the visual analysis of the entire dentition. It should be noted that the boundary criteria of the vestibular and lingual surfaces of each tooth framed in this test are not defined in the anatomical sense, but rather the criteria for the vestibular and lingual surfaces under clinical visual inspection, with the boundaries on both sides of each tooth surface located between the proximal contact areas.

In order to detect different levels of dental plaque, each participant underwent plaque recording and evaluation at two different stages, including after 24 hours without oral hygiene (T1) and after habitual brushing (T2). Subsequently, the data from the 3D image analysis of different dental surfaces were calculated at T1 and T2 respectively, and compared with the plaque index obtained from the clinical examination. When performing the analysis of the correlation between image measurements and clinical examinations, the sample size was increased by using teeth rather than individuals, which improved the confidence of the results. The clinical examination and image analysis were done by different researchers, and the latter did not know the results of the former examination, avoiding the influence of human factors on the results of image analysis. Nonparametric statistical analysis was chosen because the dental plaque index was a rank variable. The results showed a high correlation agreement between the two at different levels of plaque and on different dental surfaces. From the Spearman correlation coefficient results, the correlation between image measurement and clinical examination was higher at the moment of T1 than at the moment of T2; and during the same moment, the correlation between the two was higher on the lingual side than on the vestibular side. Overall, the agreement between the image analysis method and the conventional plaque index was better in the case of higher levels of plaque accumulation, which is consistent with our expectations. The clinical examination index chosen for the experiment was the Turesky modified Quigley-Hein plaque index, which was scored as follows: 0 = no plaque; 1 = separate flecks of dental plaque at the cervical margin of the tooth; 2 = a thin continuous band of plaque (up to 1 mm) at the cervical margin of the tooth; 3 = a band of plaque wider than 1 mm but covering less than one-third of the crown of the tooth; 4 = plaque covering at least one-third but less than two-thirds of the crown of the tooth; and 5 = plaque covering two-thirds or more of the crown of the tooth [17-18]. From this, it can be seen that the plaque index scores are not entirely based on quantitative criteria, especially in the case of small amounts of plaque (scores 0-2) which are more dependent on the subjective visual assessment of the researcher. In the case of relatively large amounts of plaque (scores 3-5), the plaque index score is judged based on the approximate proportion of plaque on the tooth surface, which is still based on visual observation, but has more definite quantitative judgment criteria, so it agrees better with the results of the quantitative analysis of the 3D images used in this study.

When performing the reproducibility test, the ICC test concluded that the results measured by the three investigators were in good agreement, indicating that the method is highly reproducible.

The 3D images acquired by the intraoral scanner in this experiment were pixelated, and their dental surface boundaries and plaque staining boundaries were more blurred compared to direct observation, which was a difficult point when processing the 3D images during this study, so the final measurement yielded a plaque percentage that was not fully representative of the actual situation. However, the subsequent statistical results showed that the calculated plaque percentages were in high agreement with the traditional plaque index and were reproducible, which indicated that even if the image quality obtained by the scanner could not fully reproduce the real situation, the color 3D information collected was reliable enough to evaluate the plaque level and could be applied in research and clinical practice.

Digital image analysis techniques are well established in the medical field, where computers are trained to discriminate, frame, and calculate 2D or 3D image information [19-21]. The current method of plaque evaluation developed in this study still relies on human processing of the images by the investigator to discriminate the tooth surface and the corresponding plaque information, and this approach needs to be improved in the subsequent research process to achieve a greater degree of automation and standardized operation mode for the 3D plaque analysis system in order to improve the efficiency and standardization of image processing.

5. Conclusion

In this study, 3D image analysis was used to evaluate dental plaque levels, providing a basis for more accurate quantitative clinical determination of dental plaque. The reliability of the method was verified in the study by comparing the results of the 3D image analysis method with those of conventional clinical examinations; the high reproducibility of the method was verified by consistency analysis of the results obtained from repeated use of the 3D image analysis method by multiple investigators. This study initially established a digital 3D evaluation system for dental plaque applicable in research and clinical practice, which can be used as a powerful tool for comprehensive analysis and documentation of patients' oral hygiene in the future.

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