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Research article

Evaluation of the accuracy of T-scan system and Cerec Omnicam system used in occlusal contact assessment

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ABSTRACT

Purpose: The objective of the present study was to determine the accuracy of T-scan system and Cerec Omnicam system with respect to the evaluation of occlusal contact by quantitatively comparing the occlusal contact areas and the overlapping ratios of occlusal contact areas obtained from these systems.

Material and methods: The occlusal contact of 20 adolescents with normal occlusion was measured with the T-scan system and the Cerec Omnicam system, respectively. The occlusal contact areas in the intercuspal position were then quantified with Adobe Photoshop CS6 Software. The same procedure was repeated for each subject using with 8 μm articulating paper as the control group. The overlapping ratio of T-scan system and Cerec Omnicam system was calculated respectively, which is defined as the ratio of overlapping areas comparing with those obtained from articulating paper. To examine the accuracy of T-scan system and Cerec Omnicam system, the Paired *t*-test was applied. The reproducibility of T-scan system was evaluated with Wilcoxon matched-pairs signed-ranks test by comparing the occlusal contact areas between two repeated measurements. In all statistical analysis, the level of significance was set to $\alpha = 0.05$.

Results: Results demonstrated measured occlusal contact areas were significantly different between those obtained between T-scan system and Cerec Omnicam system ($P < 0.05$). The tooth position of two-dimensional virtual dental arch established by T-scan system based on the width of the central incisor was in disagreement with the actual tooth position. The overlapping ratios obtained from Cerec Omnicam system were higher than those obtained from the T-Scan system ($P < 0.05$). The sensitivity of T-Scan system in anterior teeth area decreased when sensors are used more than once ($P < 0.05$).

Conclusions: In the intercuspal position, the accuracy of Cerec Omnicam system for occlusal contact assessment is higher than that of T-scan system. The T-scan system demonstrates good reproducibility in the premolar region and the molar region, but poor reproducibility in the anterior teeth region.

Clinical implications: In the intercuspal position, Cerec Omnicam system is more accurate than T-scan system, which can quantitatively analyze occlusal relationship in terms of number, position, size and distribution of occlusal contact points. When evaluating occlusal contacts, the accuracy of T-scan system in anterior teeth region is significantly lower than that of premolar and molar regions.

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1. Introduction

In accordance with the Glossary of Prosthodontic Terms, occlusion is defined as a static relationship between the contact surfaces of the upper and lower teeth, which needs to be balanced to the greatest extent [1]. Simultaneous contact of all posterior teeth and uniformly distributed occlusal forces are essential for the ideal occlusion [2]. Therefore, the assessment of occlusal contact areas is essential in clinical scenarios. During occlusal treatment, accurate measurement of occlusal contact can provide valuable information for the establishment of occlusal harmony [3].

To provide a theoretical basis for the diagnostic purposes of occlusion-related diseases such as occlusal interference and temporomandibular disorders (TMD), occlusal indicators which can locate and define occlusal contact are used for the evaluation of occlusal relationship. On the basis of their measurement capabilities, a wide range of existing indicators can be roughly divided into two categories, conventional and digital indicators. For conventional indicators, such as articulating paper and foil, only the location and number of occlusal contacts can be determined. However, these indicators such as have been irreplaceable for clinical daily practice. Digital indicators, such as T-scan system, come with the added capability of measuring the time and force to dynamically analyze occlusal contacts and record the distribution of occlusal force in different regions [4]. Aided by the T-scan system, dental arches could be imported digitally to help clinicians analyze occlusal contacts more accurately. However, the reproducibility of T-scan system are still controversial. Results from previous studies have showed that T-scan system could be a fast way to record and analyze the occlusal contacts and confirmed the valuable reliability of this device [5,6]. However, other researchers reported that the sensitivity of the T-scan sensors decreased when they are used more than once [7]. In addition, occlusal relationships may change when putting the sensor film into the oral cavity.

With the rapid development of digital technology in stomatology, dental practitioners can scan the dental arches and obtain occlusion relationship in a 3D manner with the help of intraoral scanner. The CEREC Omnicam system has introduced the possibility of evaluating the occlusal relationship at the design stage with the help of its occlusion mode, which is different from the T-Scan system and conventional indicators. This method eliminates the disadvantages of T-scan sensor and enables the practitioners to digitally evaluate the number, location, size and distribution of the occlusal contacts [8]. However, the accuracy of intraoral scanner such as CEREC Omnicam remains controversial [9]. In previous studies, the accuracy of digital interocclusal record and T-scan system was evaluated qualitatively by comparing the numbers and distribution of occlusal contacts to those obtained using the articulating paper [10]. However, there are very limited research studies to quantitatively evaluate the accuracy of occlusal indicators by comparing occlusal contact areas. It is therefore important to the ease and quantification of new digital equipment for digital analysis of occlusal contacts and to make it easier for the beginning clinician.

Accordingly, the objective of this study was to determine the accuracy of T-scan system and Cerec Omnicam system with respect to the evaluation of occlusal contact areas to provide a reference for the clinical application of digital occlusal reconstruction and diagnosis of occlusion-related diseases. Numerous previous studies have already been conducted comparing the digital indicators with articulating paper in toothed arches [10]. However, in this study, a specific method was used to analyze the accuracy of T-scan system and Cerec Omnicam system for occlusal analysis by quantitatively comparing the overlapping ratio with respect to results measured by 8 μm articulating paper, respectively. The study hypothesis was that the Cerec Omnicam system presented higher accuracy with T-scan system for occlusal contact measurement.

2. Materials and methods

2.1. Subjects

The study protocol was approved by the institution's ethics committee and was performed in accordance with the principles of the Declaration of Helsinki (No. [2019]-R-76). Subjects that fulfilled the following inclusion criteria were recruited: (i) a full permanent

Fig. 1. Oocclusal contacts of upper left teeth photographed by digital camera.

dentition of at least 28 teeth; (ii) no restorations, no dental defects, and healthy teeth and periodontal tissue; (iii) normal occlusal relationship with opposing posterior teeth in contact during lateral excursions; (iv) the intercuspal position was stable. The following exclusion criteria were applied: (i) anterior open occlusions absent of anterior guidance contacts; (ii) subjects who had experienced prior treatment for TMD or occlusal adjustment treatment. Written informed consent was obtained from 20 adolescents. For each subject, the head position was adjusted so that the headrest can be parallel to the floor in the Frankfurt horizontal plane. Besides, the maxillary and mandibular dentition were isolated and dried using an air syringe before the experiment. All tests are completed by the same experienced and trained examiner. To achieve standardization between different methods, recordings obtained from T-Scan system and CEREC Omnicam system were taken consecutively without changing the subject's position.

2.2. Occlusal contact measurement

A colored articulating paper (Arti-Fol 8 μm, Dr. Jean Bausch Gmbh & Co. KG, Germany) was placed between the occlusal surfaces of the maxillary and mandibular teeth, the subjects were asked to close the mandible and to occlude on the articulating paper with maximum force, marking the occlusal contacts in the intercuspal position. The occlusal contacts of upper left teeth were photographed and these images were collected for analysis (Fig. 1).

Digital scans of the maxillary and mandibular dental arches were made using an intraoral scanner (Cerec Omnicam, Sirona, Germany). Based on the principle of stereophotogrammetry, CEREC Omnicam system can scan the dental arches and obtain occlusion relationship in a 3D manner. The camera of CEREC Omnicam system was placed in the mouth. Starting in the center of the occlusion, data were obtained by moving the scanner to the mesial, lingual, distal, and buccal surfaces in succession. Images of the lower jaw teeth, upper jaw teeth were obtained, respectively. Then, the subject was instructed to bite with maximum force, and the buccal surfaces of the teeth were captured in order to automatically match the dental arches and generate the occlusal contacts in the intercuspal position. The virtual dentition was rotated to demonstrate occlusal contacts marked in the intercuspal position. Imagines of contacts marks on the upper left teeth were saved (Fig. 2).

The mesiodistal width of the maxillary central incisor was measured by a vernier caliper. The measured width was input into the companion software of T-scan system (T-Scan software version 8, TekScan, USA) to establish a virtual two-dimensional dental arch model for each subject. An appropriately-sized sensor of T-scan system (T-scan III, TekScan, USA) was selected based on the size of dental arch. To adjust the sensitivity of the sensor to each subject, a first and single bite recording was taken. Then, subjects were asked to occlude on the recording material up to 3s with maximum force from mandibular postural position to intercuspal position. This procedure was performed two times for each subject. The contact marks of upper left teeth were recorded (Fig. 3).

2.3. Data synthesis

The recorded images of contact areas obtained from articulating paper, T-scan system and Cerec Omnicam system were recorded in. jpeg format and then processed using Adobe Photoshop CS6. Because the sensor of T-scan system is about 100 μm thick, in this study, to ensure accurate comparison, the detection distance of Cerec Omnicam system was set to 100 μm. All areas less within this distance were recorded, while areas beyond the 100 μm detection distance were regarded as the non-occlusal contact areas.

The number of pixels in occlusal contacts of each subject in all measurements obtained with the three methods was determined with pixel-based photographic procedure program of Adobe Photoshop CS6. After determining where the occlusal contact areas were, their sizes were measured. Then, the images were overlapped with the help of picture processing techniques. Using images obtained by articulating paper as reference, images obtained by T-scan system and Cerec Omnicam system were rotated and adjusted to align and overlap with the control group by overlapping the teeth (Figs. 4 and 5). Overlapping areas of T-scan system or Cerec Omnicam system with were obtained, and overlapping ratios were calculated based on the overlapping areas. To evaluate the sensitivity of T-scan system when the sensors are used more than once, the differences of occlusal contact areas between two measurements were

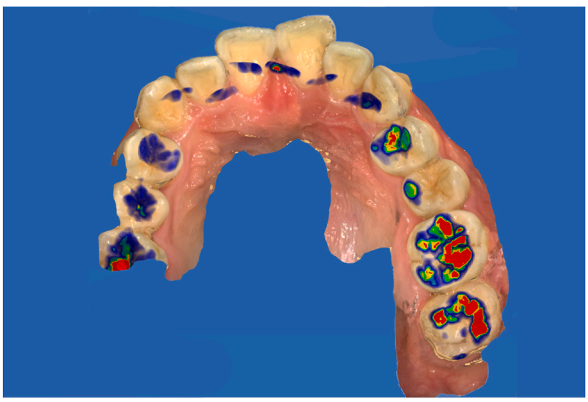

Fig. 2. Occlusal contacts of upper left teeth obtained by Cerec Omnicam system.

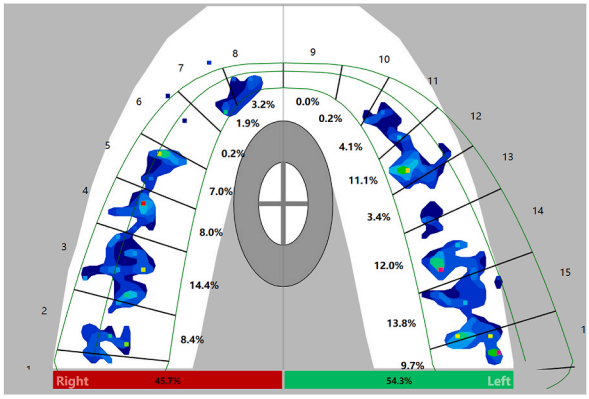

Fig. 3. Occlusal contacts of upper left teeth obtained by T-scan system.

compared.

2.4. Statistical analysis

SPSS 27.0 software was used for statistical analysis of data. Paired *t*-test was performed to analyze the differences of occlusal contact areas and overlapping ratios in occlusal contact areas between T-scan system and Cerec Omnicam system. The reproducibility of the T-scan system was evaluated with Wilcoxon matched-pairs signed-ranks test by comparing the occlusal contact areas of two measurements. The difference was considered as statistically significant when P value < 0.05.

3. Results

Results obtained from Cerec Omnicam system were consistent with those detected by articulating paper when qualitatively comparing the distribution of occlusal contact areas using images obtained by each method. Teeth positions of two-dimensional virtual dental arch established by the T-scan system based on the mesiodistal width of the central incisor were in disagreement with actual teeth positions (Figs. 4 and 5).

Contact areas of the anterior teeth, premolar and molar regions of the upper left teeth, obtained by three methods, were compared. Results showed that the distribution trends of occlusal contact areas measured by the three methods were basically the same: the molar region had the largest occlusal contact area and the anterior teeth region had the smallest. The occlusal contact area measured by Cerec Omnicam system was smaller than that measured by T-scan system, and the difference was statistically significant ($P < 0.05$) (Fig. 6A–D).

The overlapping area of occlusal contact and the overlapping ratio of T-scan system or Cerec Omnicam system with respect to the articulating paper was calculated, respectively. The result showed that the overlapping ratio of Cerec Omnicam system was higher than that of the T-Scan system ($P < 0.05$). In the intercuspal position, there was no significant difference in overlapping ratios between T-scan system and Cerec Omnicam system in premolar and molar regions ($P > 0.05$), while the difference in anterior teeth region was statistically significant ($P < 0.05$) (Fig. 7A–D).

The occlusal contact area of three different regions from the two T-scan system measurements was calculated and compared.

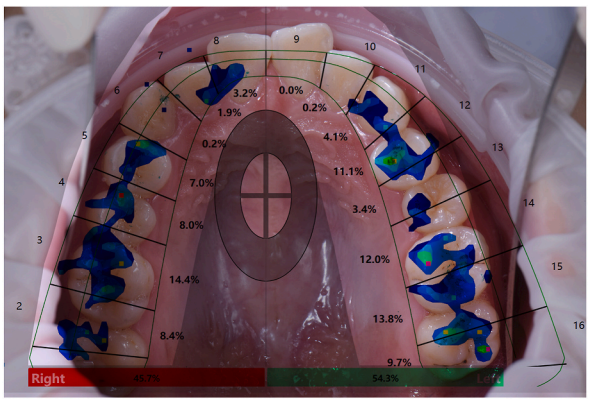

Fig. 4. Overlapping images between articulating paper and T-scan system.

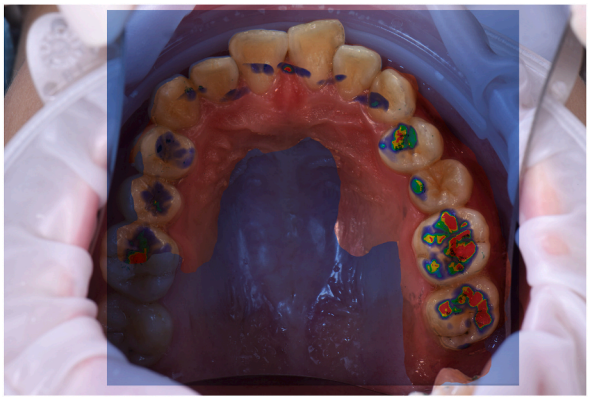

Fig. 5. Overlapping images between articulating paper and Cerec Omnicam system.

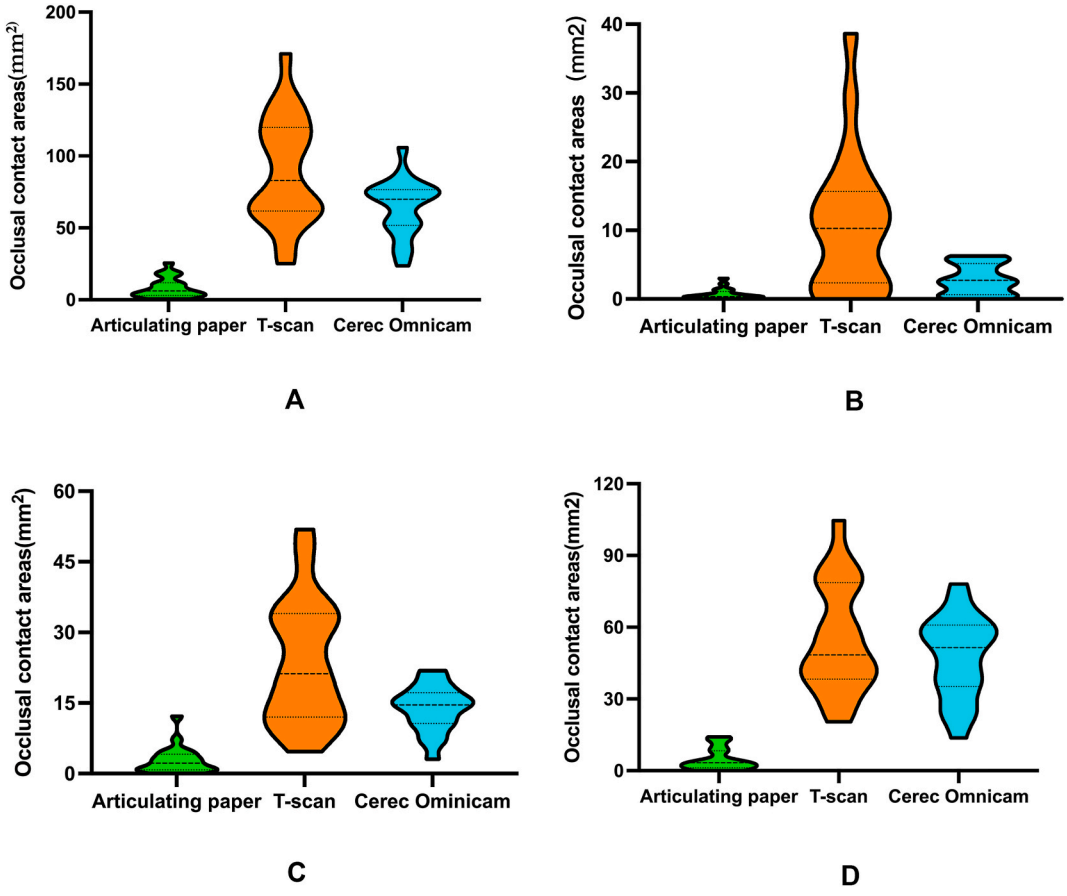

Fig. 6. The occlusal contact area measured by articulating paper, T-scan system and Cerec Omnicam system. (A, anterior teeth; B, premolars; C, molars; D, complete dentition).

Difference between the repeated measurements for the premolar and molar regions was not statistically significant, while that for the anterior teeth region was statistically significant ($P < 0.05$) (Fig. 8A–D).

4. Discussion

The present study was performed to assess whether the Cerec Omnicam system presented high accuracy with T-scan system for occlusal contact measurement. The results of this study showed that the overlapping ratio of Cerec Omnicam system was higher than

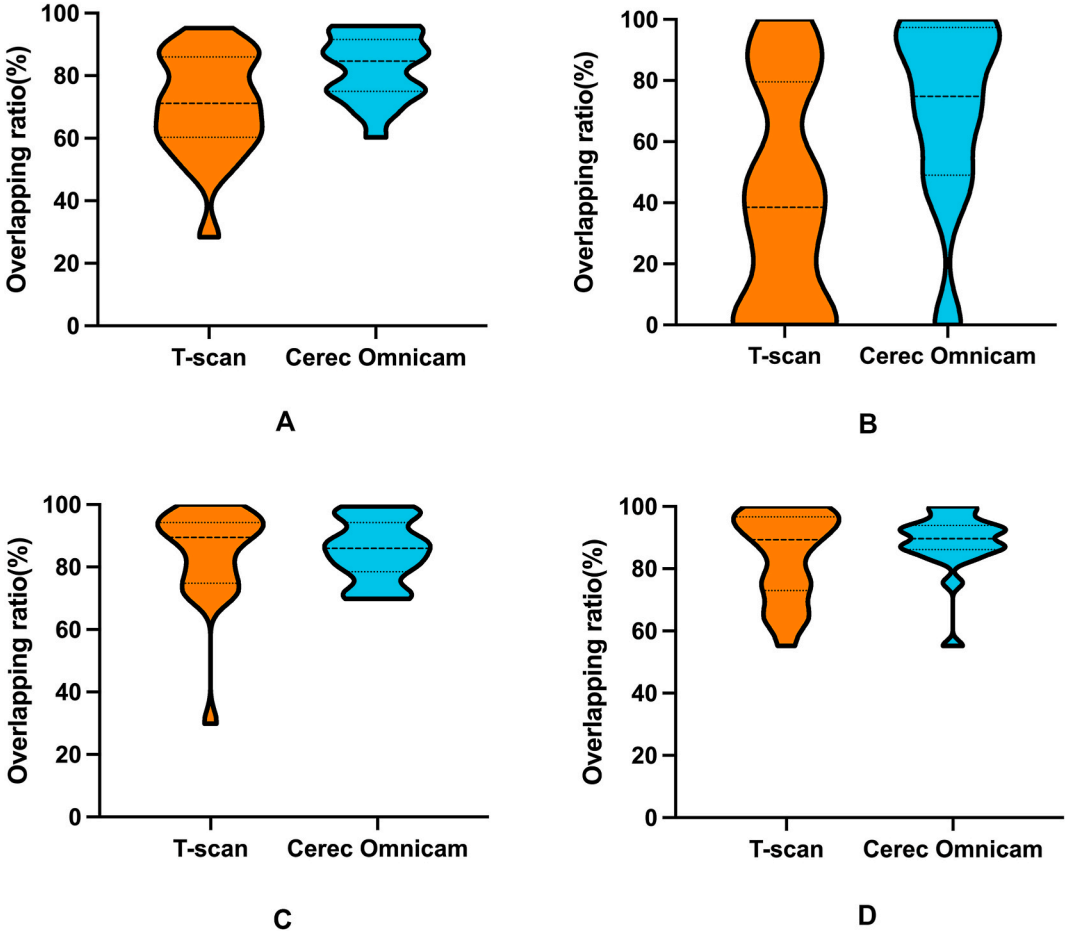

Fig. 7. The overlapping ratios of T-scan system and Cerec Omnicam system (A, anterior teeth; B, premolars; C, molars; D, complete dentition).

that of the T-scan system ($P < 0.05$), which indicates higher accuracy for occlusal contact measurement using the Cerec Omnicam system.

Tooth occlusion plays an important role in the health of temporomandibular joint, nerve, and muscle [11,12]. Therefore, the measurement and analysis of occlusal contact is of great significance in the field of prosthodontics. To make an accurate diagnosis and minimize possible mistakes in occlusal analysis, a number of methods, including articulating paper, silk strips and foils, are currently used during clinical treatments to determine occlusal contacts [13]. Because of the low cost and easy application, conventional indicators such as articulating paper are used primarily by the dental community. Published studies on occlusal indicators have demonstrated that their thickness should be less than 21 μm, so patients will not feel them in their mouth [14]. Malta et al. [15] have found that there exists some differences between the labeled thickness and actual measured thickness for some of the currently available occlusal materials. The actual thickness of Arti-Fol 8 μm articulating paper was 19.8 μm, which is within the range of ideal thickness. Accordingly, to reduce the influence of the thickness of articulating papers and provide accurate conclusion, the Arti-Fol 8 μm articulating paper from Dr. Jean Bausch Gmbh & Co. KG was selected as the control group in this study. The primary objective of the present study was to evaluate the accuracy of occlusal contact assessment between T-scan system and Cerec Omnicam system. Accordingly, there should be a control group measured by articulating paper to define the overlapping ratios of T-scan system and Cerec Omnicam system in this study. In addition, studies have shown that wet environment had a significant impact on the occlusal results and drying the mouth thoroughly before testing therefore may affect the success of occlusal analysis [16]. Therefore, to improve the reliability of occlusal analysis, the maxillary and mandibular dentition was isolated and dried using an air syringe before the experiment.

The mandible position was influenced by the position of the body. Different occlusal contacts can be recorded in the same subject because of various chair angles and head inclination [17]. In addition, a previous study reported that the longest occlusion time could be detected in the horizontal position [18]. The objective of this study was to compare the occlusal contact areas obtained from three methods in the same position. Therefore, to achieve standardization, recordings were taken from the same head position for each subject, which was adjusted to be parallel to the Frankfurt horizontal plane. Moreover, to minimize the potential practitioner-origin differences, recording procedures were conducted by the same experienced operator.

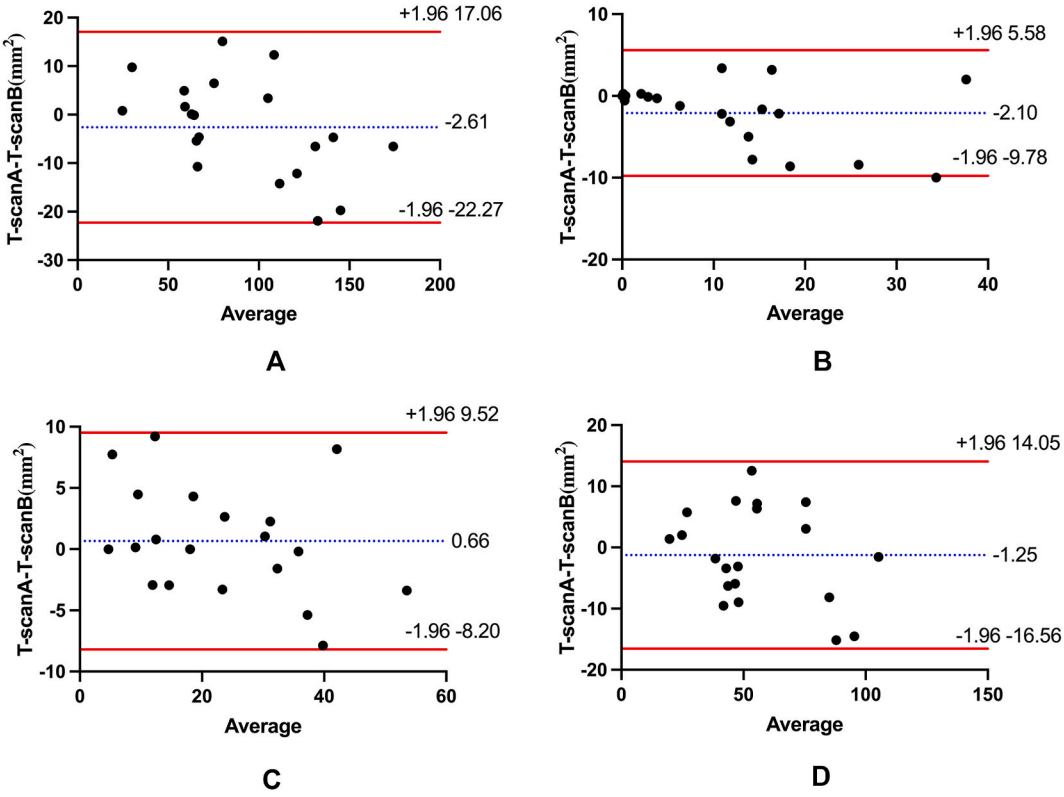

Fig. 8. The differences of occlusal contact areas between two T-scan system measurements (A, anterior teeth; B, premolars; C, molars; D, complete dentition).

With enabled data transmission by connecting with a computer, the T-scan system can record the location, range and occlusal force of each occlusal contact point, as well as changes of these occlusion characteristics over time. However, it should be emphasized that different subjects have various bite force, which affects the intensity of contact of the teeth. Accordingly, in the present study, the sensitivity of sensor in T-scan system was individually adjusted before each recording to eliminate the potential differences from individual bite forces. Tosa et al. [19] reported that 68% of incisors had an interocclusal space of more than 60 μm and occlusal contact points were concentrated in the molar region while the anterior teeth were not in contact. The thickness of T-scan sensor is about 100 μm, false contact imprint will be formed when this thickness exceeds the height of non-occlusive space. Furthermore, when placed between the maxillary and mandibular teeth, it might interfere with the subject, and cannot fully reflect the occlusal contact information. Forrester et al. [20] have found that the plastic T-Scan sensor can change surface electromyography activity during occlusion, which may affect the reliability of the measurement. Results of this study showed that in the anterior teeth region, the accuracy of the T-scan system was significantly lower than that of the premolar and molar regions, which indicates that it is not accurate enough for determining the occlusal contact of anterior teeth. In addition, when aligning and overlapping the two-dimensional views between the T-scan system and control group, we found that the tooth position in the two-dimensional virtual dental arch established by the T-scan system based on the width of the central incisor was in disagreement with the actual position.

During the measurement, many subjects mentioned that the comfort of occlusal movement was affected by the bulky T-scan sensor. Due to this change in oral cavity, the coordination of masticatory muscles was affected and the occlusal position of subjects was changed. Moreover, the elasticity of the T-scan sensor was reduced because it was tightly fitted with the handle. Currently, the reproducibility of the T-scan system is still controversial. In this study, Bland-Altman method was used to measure the calculated occlusal contact areas obtained by T-scan system for two repeated measurements. The results of Fig. 8A–D demonstrated no significant difference in the premolar region and molar region and complete dentition ($P > 0.05$), but the difference in anterior teeth region was statistically significant ($P < 0.05$), indicating that the T-scan system has good reproducibility in the premolar area and molar regions, but poor reproducibility in the anterior teeth region.

Currently, dentists' understanding of occlusal contact recorded by articulating paper depends on subjective judgments such as color and area. By measuring different applied occlusal load using articulating paper, Carey et al. [21] reported that no direct relationship between the scope of marked regions and magnitude of the applied occlusal load could be found, despite the trend of increasing marked area with elevating load. Recently, digital technology has developed rapidly in the field of stomatology. Three-dimensional virtual dentition can be obtained using an intraoral scanner. With this method, the occlusal contact areas can be obtained more accurately, and the occlusal relationship can be analyzed more objectively. In addition, it avoids the disadvantages of T-scan system to

some extent because it does not rely on the detection medium. By generating three-dimensional dentition through continuous optical image acquisition, the Cerec Omnicam system can clearly display intraocclusal distance based on the color change, which indirectly reflects occlusal force and can analyze occlusal contact more accurately [22]. After using Paired *t*-test to evaluate the overlapping ratios between T-scan system and Cerec Omnicam system, The results of Fig. 7A–D indicated the accuracy of occlusal contact measurement of Cerec Omnicam system was higher than that of the T-scan system in terms of the anterior teeth region and complete dentition, while no significant difference was found in premolar and molar regions.

In the process of intraoral scanning, continuous focusing and image acquisition result an enormous amount of data being collected. Due to the limitation of data processing capacity, the obtained details of occlusal pits and fissures are not consistent with the actual situation, which increases the difficulty of recording occlusal relationship and affects the accuracy of scanning to some extent. A previous study reported that the precision of intraoral scanning is clinically acceptable when the scanning scope is less than half arch, but it decreases as the scanning scope increases [23]. To avoid scanning bias, in this study, the Cerec Omnicam system was used to scan the upper left teeth. The results showed that the number of occlusal contact points and the shape of the teeth captured by this system were basically the same as those of the control group, although the relative position of dental arch was still partly deviated, which indicates that the Cerec Omnicam system may be valuable for clinicians with respect to occlusal contact assessment. In addition, because the Cerec Omnicam system mainly captures images of soft and hard tissues in the oral cavity, due to the complex occlusal surface for molar, it is relatively difficult to target the shapes of occlusal surface accurately during the scanning process, which affects the accuracy.

The present study has some limitations. First of all, to analyze the reliability of the digital occlusal contacts, it is necessary to compare with a gold standard. Accordingly, the articulating paper was used as the control group in the present study. However, the density interpretation in areas marked with this indicator may be subjective to a certain extent. Since we focused on the occlusal contact areas of upper left teeth to determine the accuracy of digital indicators, we did not scan the complete dentition to improve the accuracy and the molar region in the upper right teeth may be influenced during the overlapping process. In addition, occlusal contacts are distributed not only in a bidimensional space but rather in a three-dimensional space. However, this study only evaluate the occlusal contacts in a 2D manner because of incompatibility of dimensions and difficulty of standardization. Based on the present study, further researches may focus on evaluating different relationships between upper and lower teeth, various bite force and distribution of occlusal contacts to provide additional references on this area.

5. Conclusions

Based on the findings of this study, the following conclusions were drawn.

1. When evaluating occlusal contacts, the accuracy of T-scan system in anterior teeth region is significantly lower than that of premolar and molar regions.
2. In the intercuspal position, Cerec Omnicam system is more accurate than T-scan system, which can quantitatively analyze occlusal relationship in terms of number, position, size and distribution of occlusal contact points.
3. When used more than once, the T-scan system has good reproducibility in premolar area and molar regions, but poor reproducibility in the anterior teeth region.

Author contribution statement

Rongkai Cao: Conceptualization, Methodology, Writing - Original Draft, Formal analysis.
Jing Lin: Investigation, Validation.
Hui Xu: Software, Data Curation.
Weicai Liu: Resources, Writing - Review & Editing, Supervision, Funding acquisition.

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Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e13476.

References

[1] K.J. Ferro, S.M. Morgano, C.F. Driscoll, M.A. Freilich, A.D. Guckes, K.L. Knoernschild, T.J. McGarry, M. Twain, The glossary of prosthodontic terms: ninth edition, J. Prosthet. Dent 117 (2021) 1–105, https://doi.org/10.1016/j.prosdent.2016.12.001.

[2] T.W. Korioth, Number and location of occlusal contacts in intercuspal position, J. Prosthet. Dent 64 (2) (1990) 206–210, https://doi.org/10.1016/0022-3913(90)90180-k.

[3] K. Ando, Y. Fuwa, M. Kurosawa, T. Kondo, S. Goto, Bite force measurement system using pressure-sensitive sheet and silicone impression material, Dent. Mater. J. 28 (2) (2009) 212–218, https://doi.org/10.4012/dmj.28.212.

[4] A. Sharma, G.R. Rahul, S.T. Poduval, K. Shetty, B. Gupta, V. Rajora, History of materials used for recording static and dynamic occlusal contact marks: a literature review, J. Clin. Exp. Dent. 5 (1) (2013) 48–53, https://doi.org/10.4317/jced.50680.

[5] B. Koos, A. Godt, C. Schille, G. Göz, Precision of an instrumentation-based method of analyzing occlusion and its resulting distribution of forces in the dental arch, J. Orofac. Orthop. 71 (6) (2010) 403–410, https://doi.org/10.1007/s00056-010-1023-7.

[6] B.A. Deepika, J. Ramamurthy, Evaluation of occlusal pattern in periodontitis patients using T-scan analysis, "J. Adv. Pharm. Technol. Research"" (JAPTR)" 13 (Suppl 1) (2022) 265–271, https://doi.org/10.4103/japtr.japtr_225_22.

[7] G.S. Throckmorton, J. Rasmussen, R. Caloss, Calibration of T-Scan sensors for recording bite forces in denture patients, J. Oral Rehabil. 36 (9) (2009) 636–643, https://doi.org/10.1111/j.1365-2842.2009.01978.x.

[8] J.M. Seo, W.S. Oh, J.J. Lee, A technique for verifying the accuracy of the virtual mounting of digital scans against the actual occlusal contacts, J. Prosthet. Dent 121 (5) (2019) 729–732, https://doi.org/10.1016/j.prosdent.2018.08.003.

[9] C.C.D. Resende, T.A.Q. Barbosa, G.F. Moura, L.D.N. Tavares, F.A.P. Rizzante, F.M. George, F.D.D. Neves, G. Mendonça, Influence of operator experience, scanner type, and scan size on 3D scans, J. Prosthet. Dent 125 (2) (2021) 294–299, https://doi.org/10.1016/j.prosdent.2019.12.011.

[10] I. de Prado, M. Iturrate, R. Minguez, E. Solaberrieta, Evaluation of the accuracy of a system to align occlusal dynamic data on 3D digital casts, BioMed Res. Int. 2018 (2018), 8079089, https://doi.org/10.1155/2018/8079089.

[11] N. Marchili, E. Ortu, D. Pietropaoli, R. Cattaneo, A. Monaco, Dental occlusion and ophthalmology: a literature review, Open Dent. J. 10 (2016) 460–468, https://doi.org/10.2174/1874210601610010460.

[12] J.L. Villaça Avoglio, Dental occlusion as one cause of tinnitus, Med. Hypotheses 130 (2019), 109280, https://doi.org/10.1016/j.mehy.2019.109280.

[13] A. Takai, M. Nakano, E. Bando, E.R. Hewlett, Evaluation of three occlusal examination methods used to record tooth contacts in lateral excursive movements, J. Prosthet. Dent 70 (6) (1993) 500–505, https://doi.org/10.1016/0022-3913(93)90262-m.

[14] G.C. Halperin, A.R. Halperin, B.K. Norling, Thickness, strength, and plastic deformation of occlusal registration strips, J. Prosthet. Dent 48 (5) (1982) 575–578, https://doi.org/10.1016/0022-3913(82)90367-5.

[15] J. Malta Barbosa, A.B. Urtula, R. Hirata, J. Caramês, Thickness evaluation of articulating papers and foils, J. Esthetic Restor. Dent. 30 (1) (2018) 70–72, https://doi.org/10.1111/jerd.12343.

[16] A. Saraçoğlu, B. Ozpinar, In vivo and in vitro evaluation of occlusal indicator sensitivity, J. Prosthet. Dent 88 (5) (2002) 522–526, https://doi.org/10.1067/mpr.2002.129064.

[17] M.F. Coelho, B.d. Cavalcanti, A.C. Claro Neves, R.P. Jóias, M. Rode Sde, Influence of dental chair backrest inclination on the registration of the mandibular position, J. Prosthet. Dent 114 (5) (2015) 693–695, https://doi.org/10.1016/j.prosdent.2015.05.013.

[18] S. Haralur, S. Al-Gadhaan, A. Al-Qahtani, A. Mossa, W. Al-Shehri, M. Addas, Influence of functional head postures on the dynamic functional occlusal parameters, Ann. Med. Health Sci. Res. 4 (4) (2014) 562–566, https://doi.org/10.4103/2141-9248.139319.

[19] J. Tosa, H. Takada, M. Tanaka, T. Kawazoe, Intraocclusal distance between the anterior teeth in intercuspal position, J. Osaka Dent. Univ. 25 (2) (1991) 83–88.

[20] S.E. Forrester, R.G. Presswood, A.C. Toy, M.T. Pain, Occlusal measurement method can affect SEMG activity during occlusion, J. Oral Rehabil. 38 (9) (2011) 655–660, https://doi.org/10.1111/j.1365-2842.2011.02205.x.

[21] J.P. Carey, M. Craig, R.B. Kerstein, J. Radke, Determining a relationship between applied occlusal load and articulating paper mark area, Open Dent. J. 1 (2017) 1–7, https://doi.org/10.2174/1874210600701010001.

[22] F.D. Oz, S. Bolay, S. Canatan, A clinical evaluation of resin nanoceramic CEREC Omnicam restorations associated with several factors, J. Esthetic Restor. Dent. 33 (4) (2021) 583–589, https://doi.org/10.1111/jerd.12691.

[23] T.S. Su, J. Sun, Comparison of repeatability between intraoral digital scanner and extraoral digital scanner: an in-vitro study, J. Prosthodont. Res. 59 (4) (2015) 236–242, https://doi.org/10.1016/j.jpor.2015.06.002.