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Review Article

Application of Digital Occlusion Analysis System in Stomatological Clinical Medicine

Gu DA[1], Miao LY[2] and Liu C[1]*

[1]Department of Orthodontics, Nanjing Stomatological Hospital, Medical School of Nanjing University, Nanjing, China

[2]Department of Cariology and Endodontics, Nanjing Stomatological Hospital, Medical School of Nanjing University, Nanjing, China

***Corresponding author:** Liu C, Department of Orthodontics, Nanjing Stomatological Hospital, Medical School of Nanjing University, Nanjing 210093, China

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Abstract

T-Scan III system is one of the most commonly used tools to analyze the bite forces simultaneously on the teeth. As the effectiveness and reliability of T-Scan III are widely studied and recognized, it has many clinical applications in dentistry for the evaluation of dental occlusion in the past decades, such as prosthodontics, orthodontics, and other subjects related to occlusion. This paper reviews the applications of T-Scan III in oral clinic in the past 10 years, and looks forward to its development and application in the future.

Keywords: T-Scan III; dynamic occlusion evaluating; clinical applications; oral medicine

Introduction

Methods for evaluating occlusal contact can be divided into qualitative and quantitative analyses. Qualitative analysis involves evaluating tooth contact and the positions of the teeth by means of occlusal film, shim stock, wax, and silicone. Through observing the various ink on the tooth surface directly, articulation paper is one of the most commonly used methods to determine excessive force in differing occlusal contacts. However, it has disadvantages such as lack of objectivity and reproducibility, as well as the difficulty of describing the various states of occlusion. Quantitative analysis involves the use of various occlusal indexes to evaluate the pretreatment occlusal state and the results of orthodontic treatment. Digital occlusal analysis as one of the most vital of the quantitative analysis methods has been shown to consistently measure relative occlusal forces in a highly repeatable fashion [1].

Most of the traditional methods are to analyze static occlusion, but occlusion is not static, rather it is a parameter of a structure with dynamic motion. Occlusion should be assessed not only based on dental casts, but also the dynamic motion included intermaxillary maximum intercuspation, protrusion, and lateral excursion should be considered. The T-Scan III system developed by Tekscan (Boston, MA, USA) uses computer to analyze dynamic occlusion, allowing both qualitative and quantitative occlusion analysis to be performed simultaneously and with great precision. It represents occlusal status in terms of quantitative values for various parameters. In addition, it can measure the sequence of tooth contact and quantitative changes in relation to time, locate excessive occlusal forces, and record the amount of time from early contact to equilibrium of occlusal forces. However, some have argued that these indexes can vary depending on who takes the measurements, rendering them less reliable in terms of precision and objectivity. According to the Bland-Altman statistical method, the accuracy of a single measurement of T-Scan III involves factor 1.96 (measurement error). The precision (repeatability and reproducibility) of the repeated registrations involves factor 2.77. With respect to the maximum total force measured, the measurement error is 1%, accuracy is 2%, and reliability is 2.8% [2]. Another study was to test the accuracy and reliability of changing the foil and repositioning the T-Scan III during the repeated measurements. They found the level of accuracy is acceptable and no interference arising when changing the foil or the repeated measuring was detected [3]. Therefore, the T-Scan system can provide the information which is more precision that cannot be obtained by traditional methods of occlusal measurement and evaluation [4]. Proponents of this occlusal analysis system claim that the recorded data on occlusal force and contact timing provides much improved information to the clinicians, as compared to the conventional methods that require subjective judgments. Lee SM. et al.'s study verified the T-Scan III system was a quantitative and reliable method for occlusal evaluation, and represented a potential substitute for occlusal indexes [4]. Bozhkova TP's study showed that the T-Scan system can provide a very accurate way of determining and evaluating the time sequence and force magnitude of occlusal contacts and allowed adjustment of imbalanced forces for every segment of the dentition [5].

The computerized analysis system is a diagnostic tool that assesses dental occlusion and finds utility in any field that requires diagnosis of the occlusion and/or occlusal balancing. The common applications in dentistry claimed by the T-Scan III promoters include those crucial to natural dentition with occlusal disturbances, implant placement, orthodontics, myofacial pain, restorative dentistry and prosthodontics, patient education, occlusal diagnosis and equilibration. This paper reviews the composition and applications of T-Scan III system in oral clinic in the past 10 years, and looks forward to its development and application in the future.

Composition and Function of T-Scan System

In 1987, Maness developed the first version T-Scan Occlusal Analysis system. Nowadays the newest version of the system T-Scan III has been modified and improved both in the software and hardware. The T-Scan III system consists of a hand-held device with a USB port to be connected to a laptop or a Windows-based PC; the hand-held device contains a U-shaped pressure-measuring sensor that fits into the patient's mouth between the occluding teeth. The software can analyze the data automatically and show them in different color 3D or 2D graphics. The simulation dentition can also be divided in anterior

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and posterior halves giving as a result 4 segments to analyze [5].

The T-Scan III sensors are available in two sizes: the larger for an arch up to 66mm wide and 56mm long, with 1370 sensels, and the smaller for arches up to 58mm wide and 51mm long with 1122 sensels. Each of the sensels that comprise a T-Scan III sensor encodes in 8 bits, giving 256 possible levels for the force exerted on it. When the patient bites on the sensor, many sensels are excited simultaneously, and the results are recorded as quantitative force data. Among the computer screen we can see a real-time movie which is scanned in time increments of 0.01 seconds of occlusal contacts from the first point of contact to maximum intercuspation (MIP). The relative forces among the occlusal contacts, teeth with excessive forces, and occlusal contact timing sequences, which illustrate the exact order of tooth contacts and the intensity of the associated forces. These forces are represented as bars and columns on the three-dimensional window, ranging from blue, which is optimum force, to green, yellow, orange, red and pink as the forces increase.

The T-Scan III system is used to register the occlusal contacts. The patient is seated on the dental chair with the lower and upper parts of his body positioned at an angle of 90º. For the purposes of familiarization, the participant is first asked to open and close his or her mouth 10 to 15 times, simulating the occlusal force to be performed. The T-Scan III sensor is inserted intraorally between the central incisors of the patient as the central mark, and then participant is instructed to clench as hard as possible with their teeth in the centric occlusion, right lateral excursion, left lateral excursion, and protrusion are measured, maintaining the same level of contraction for 5s. Three times readings are taken, and the mean is used for analysis. Readings are taken before and after treatment.

When a patient bites or makes movements across the recording surface to monitor the distribution of occlusal points, T-Scan III allows assessment of the following parameters: Occlusion time-the time from the first contact of the teeth to the maximum intercuspidation (reference value in patients with natural teeth <0.2s). Disclusion time - the time from the maximum intercuspidation to obtain complete lack of the teeth contact in lateral movement on one side, to the right or to the left (reference value in patients with natural teeth <0.4s).So far, many studies have confirmed the advantages of the T-Scan III system in evaluating occlusal contact according to the above parameters and the system is regarded as a useful clinical method that eliminates a biased subjective evaluation of the occlusal and articulating relations on the part of an operator [6].

An important requirement for the clinical applicability of a measurement system is that the values provided represent the real values with the greatest possible accuracy. This is essential for establishing the occlusal harmony [7]. Wang et al. [8] asserted that saliva in the oral cavity does not affect the T-Scan system's recording process. Similarly, other clinical and laboratory research has confirmed the pressure sensitivity, accuracy, and stability of relative force loadings and the reproducibility of results obtained via the T-Scan system [4]. According to the manufacturer, T-Scan III sensors can be used up to 15 to 25 times while still retaining high standards of reliability. Accordingly, for each participant, the same sensor can be used throughout the adjustment and recording procedures to eliminate any intersensor variability [9].

Based on the above composition characteristics and usage, this paper reviews the specific applications of T Scan III system in oral related fields in the past ten years, and looks forward to the future development direction.

Clinical Application in Prosthodontics

Crowns, fixed partial dentures, and removable dentures are the popular prosthetic dental restorations in current dental practice [10]. Occlusion plays an important role in the retention, stability and exerting masticatory function of dental restorations. Through analyzing the occlusal condition and bite force of the teeth, the destructive occlusal stress contact can be eliminated, so that we can achieve accurate jaw adjustment, solve the problem of bite unbalance. The T-Scan III system can accurately identify occlusal force distribution and the sequence of occlusal time in natural teeth and prostheses. Compared with the traditional occlusal detection method, using T-Scan system to instruct the selective polishing is more sensitivity and can guide more accurate occlusal adjustment in prosthodontics [11].

The T-Scan III can be used to analyze the relative occlusal forces distribution at left and right, anterior and posterior quadrants [12]. Through using the T-Scan III digital occlusal system record anterior and posterior percentage occlusal force (%OF) distributions, Khuder T et al. [13] compared residual ridge resorption (RRR) of anterior and posterior maxillary and mandibular edentulous ridges, in patients treated with mandibular implant overdentures and compare with conventional complete dentures, and to determine at each location, the association of RRR with the occlusal forces distribution and other patients' variables. Another study reported using the T-Scan system to analyze and measure occlusal forces before and after the complete removable denture treatment, and with the computer-guided corrective adjustments, the occlusal balances can measurably improve [14,15].

Implant failure has often been associated with excessive occlusal forces acting on implant prostheses. Such forces can cause the loss of bone, cementation compromise, screw loosening, and failure of materials. Though describing and analyzing the longitudinal variation of occlusal force distribution and occlusal time, the T-Scan III system was used to evaluate the relation between occlusal loading and peri-implant clinical parameters in patients with fixed implant-supported prostheses [16,17]. The T-Scan III system enables the clinician to measure occlusal forces before implantation so that remediation of aberrant forces can be initiated. Yu et al. [18] used T-Scan III system to evaluate the clinical, occlusal and biomechanical performance of 1-piece and 3-piece designs for implant-supported fixed dentures in the edentulous mandible. They found on the basis of ensuring oral hygiene, the 1-piece framework design might be the more optimal therapy for restoring an edentulous mandible, based on occlusal and biomechanical outcomes.

Basso et al. [19] used T-Scan III to assess possible changes in the occlusion contact areas of dentures after disinfection. They found microwave disinfection protocols did not influence occlusal contacts of the complete dentures. They also found that microwave irradiation might be a reliable alternative to conventional methods of disinfection of complete dentures without damaging the denture materials and might contribute considerably to treating and preventing denture

stomatitis. Through recording occlusal contacts, T-Scan III was used to confirm whether placement of a SSC changes the maximum intercuspation position (MIP) in children, whether the MIP returns to normal within 4 weeks and whether local anaesthesia had an effect on the child's ability to achieve MIP [20].

Clinical Application in Orthodontics

Stable occlusion is one of the most important parts of the result of malocclusion treatment. In other words, it is not only the main goal of orthodontic treatment, but also an important basis for maintaining the long-term stability of orthodontic effect. The T-Scan system can record bite force dynamics, including relative occlusal force, location, and timing, so it was used to record the occlusal force discrepancy in the post-orthodontic subjects. Alkayyal et al. [21] found that there were significant associations between the distribution of occlusal balance and Angles' classes of occlusion, skeletal relationship, overjet, overbite, and space analysis while the lateral occlusal schemes were only associated with Angle's classes of occlusion and skeletal relationship. Another study demonstrated that computerized occlusal analysis could provide objective insight into the differences in occlusal parameters between a naturally developing occlusion and a post-orthodontic occlusion. What's more, when compared to the natural dentition subjects, they found a significant occlusal force discrepancy in the post-orthodontic subjects, with higher force percentages observed posteriorly and much less percentage force anteriorly [22].

Nowadays, the absence of quantification is a huge drawback for the orthodontic treatment results, as the clinician cannot visually determine any true occlusal force imbalances present, nor determines whether excessive occlusal force concentrations are present on the 2nd molars (or other teeth for that matter) [22]. Digital methods of analyses conducted give new opportunities for better understanding of occlusal biomechanics, so it was recommended to be applied during orthodontic case finishing and occlusal balancing procedures, to achieve a highly balanced occlusion for an improved treatment outcome [23]. A study using the T-Scan system has reported that some occlusal features, such as dental and skeletal Angle's Class, overjet, and overbite can affect bite force distribution; specifically, Class III subjects (both dental and skeletal). The results reminded us those patients with dental and periodontal pathologies (such as oral parafunctions and bruxism) that might be affected by excessive tooth stress, so the occlusal force imbalance should be minimized before removing the orthodontic appliances [24].

Complying with functional occlusion criteria is one of the most important steps in maintaining stable results at the end of a treatment. Retention is an integral step of orthodontic treatment, patients require permanent retention when the bite is not stable, and without such permanent retention, the malocclusion will return. In order to hold the teeth in their post-treatment position, the excellent occlusal contact should be taken into account during the orthodontics treatment. There are many other studies evaluating the computerized occlusal analysis of patients wearing vacuum-formed, hawley and bonded retainers, and the results showed the T-Scan system can provide a detailed analysis of occlusion during maximum intercuspation especially in the occlusal surface area and the occlusal force distribution in the anterior and posterior dental arches [25,26].

Computerized occlusal analysis is an objective diagnostic tool determining the quality of excursive movements during orthodontic treatment. Therefore, there are many studies reporting the importance of occlusion in orthodontics. A study evaluated the disclusion time in the lateral excursions and protrusion among subjects with Angle's malocclusions by using a T-Scan III system [27]. Another study investigated measured excursive movement occlusal contact parameters and their association with TMD symptoms between non- and post-orthodontic subjects [28]. The T-Scan III device was also used to evaluate the effects of modified bonded rapid maxillary expansion on occlusal force distribution [29].

Clinical Application in Oral and Maxillofacial Surgery

A mandibular position that determines occlusal, muscular, and articular balance is required to plan and execute oral rehabilitation, in concordance to the stomatognathic system [30]. Many researchers have studied occlusal contacts and their possible relationship with the temporomandibular disorder (TMD) [31,32]. However, no study has been able to clarify whether changes in the distribution of occlusal contacts occurred before or after the onset of TMD or their role. Ferrato G et al. [33] reported that using T-Scan III to study the occlusal forces comparing healthy subjects and TMD patients. After that, T-Scan technology, as a good tool for the assessment of occlusal discrepancies, can provide comprehensive information about a patient's occlusion and can help clinicians assess treatment outcomes [34]. So far, there have been many studies using T-Scan III system to evaluate the relationship between occlusion parameters and the TMD. A Study to determine the prevalence of TMD in a young adult population found that the prevalence of TMD in university student population was 17%, the associations of TMD with psychological parameters and functional occlusal parameters were significant [35]. Through recording the dynamic parameter of OT, a study reported that using T-Scan III to evaluate the effect of low-level laser therapy on pain, mandibular movements, and occlusal contacts in adolescents and young adults with TMD [36].

T-Scan had a high degree of reliability for consecutive measurements (Pearson correlation, r=0.98). It's a good tool for the assessment of occlusal discrepancies and can be useful during both treatment planning and the follow-up period, especially in orthognathic surgery patients. The system may also allow relapse to be detected earlier [37]. A recent study has reported that periodically used T-Scan to assess the occlusion in mandibular condyle fractures who treated with Erich arch bar and guiding elastics [38]. Thumati P [39] used T-Scan III and electromyography to assess the treatment of occlusally activated orofacial pains.

Through using the T-Scan III to estimate the left/right distributing percentage of occlusal force, Zheng S et al. [40] investigate the severity and the natural course of masticatory muscles weakness that developed after CT-guided percutaneous trigeminal radiofrequency thermocoagulation for the treatment of idiopathic trigeminal neuralgia. Liu et al. [41] used the T-Scan III system to evaluate occlusal function in mandibular reconstruction patients, the results showed the size of a reconstruction did not affect the occlusal force after reconstruction and larger reconstructed areas did not decrease the average occlusal force.

Clinical application in the Department of Internal Stomatology

T-Scan can record the sequence of bite contact and the percentage (%) bite force distribution to the left and right sides compared with maximal occlusal force [42]. Therefore, in one study, T-Scan was used to record preoperative and postoperative occlusal loads on the patients who were diagnosed as symptomatic apical periodontitis and endodontically treated tooth and the effect of occlusal reduction on postoperative pain was also evaluated. The result showed that occlusal reduction, determined using a computerized analysis system, did not influence the postoperative pain in teeth diagnosed as symptomatic apical periodontitis [43].

Other Applications Related to Occlusion

Occlusal function is not only an important research content in stomatology, but also closely related to other health. A study investigated the number of residual teeth, subjective mastication comfort, and subjective food mastication ability to determine the degree of mastication in elderly women. Another study by using the T-Scan III system measured occlusion contact and the objective mastication performance while chewing gum confirmed an association between cognitive function and mastication ability especially posterior occlusion force. Moreover, they found the elderly having more occlusion force of posterior teeth rather than anterior teeth were associated with better cognitive ability. Therefore, it may be important for the elderly to restore the masticatory function for the posterior part to prevent against deterioration of cognitive function [44].

T-Scan is used as a gold standard because it is a computerized occlusal analysis that is developed for quantitative clinical use. Though analysing the bite force in MIP among patient's perceptions, clinician subjective interpretation, and T-Scan III system, the result showed clinician subjective interpretation was more consistent with T-Scan III when compared with patient's perception in term of occlusal force in MIP, therefore, clinically dependable than patient's perception. Additionally, data from patient's perception alone should be used with cautious especially for irreversible dental treatment [45].

The occlusal force of the bruxism patients was measured by T-Scan which was used as the 'gold standard' for comparison with the occlusal force predicted by the mode. The result showed there was a high degree of agreement between the occlusal force of the patient measured using T-Scan III and the occlusal force predicted by the model (kappa value = 0.82) [1]. Through T-Scan III occlusal analysis system analyzed the distribution of occlusal contacts, Silva et al. studied the prevalence of temporomandibular disorder (TMD) in a sample of patients with Parkinson's disease [46].

Occlusal contacts in bruxism patients and controls with normal occlusion were evaluated by T-Scan III before splint therapy and 3 months after therapy. The results of this study showed the use of a stabilization splint may not have an effect on occlusion [47]. Di Berardino et al. investigated the patterns and forces of occlusal contacts with the T-Scan III occlusal imaging and analysis system in patients affected by tinnitus. The result showed the clinical role of the analysis of COT in the intercuspal position (ICP) using the T-Scan III system might be useful to decide a possible and verify the effects of specially designed occlusal devices that recently have been proved to reduce the entity of tinnitus [48].

There were some studies reporting that T-Scan III system and BioEMG system were used to record bite force, occlusal contacts and SEMG activity of the anterior temporalis and of the masseter muscles simultaneously. A study using the simultaneous recording systems for occlusal contacts, bite force and SEMG signals, concluded that the maximum of bite force could be achieved with a submaximal level of jaw-closing muscle SEMG activity in the well-balanced maximum intercuspal relation with the maximum number of occlusal contacts [49].

Another study used T-Scan III to analyze the occlusal contact points and the results indicated that the symmetry of sEMG activity in asymptomatic young adults is not related to symmetry of occlusal contacts [50].

Conclusion and Prospect

Digital evaluation of the occlusion with the T-Scan system enables the clinician to evaluate the occlusal contacts quantitatively and record the occlusion during continuous mandibular movement and will provide additional information such as occlusion and disclusion time on functional occlusion. It would benefit many dental medicine disciplines to recognize the significant advance in occlusal diagnosis and treatment the T-Scan system has represented since its inception 30 years ago [51]. However, the T-Scan III system cannot measure the absolute value of occlusal force [4], and the accuracy and limitations of the measurement for patients with malocclusion, such as crossbite, deep overbite of anterior teeth and open bite need to be further improved. What's more, among other disadvantages, there is the operator dependent factor (to some extent) and the fact that the sensor is not always appropriate for all arch shapes, and the sensor may induce an alteration of the mandibular movements and create discomfort when placed intraorally [11], so a study recommended that the computerized occlusion analysis should be carefully considered in patients affected by TMJ problems when it as adjunctive instrumental device [52].

For the further development of the T-Scan system, future investigation will endeavour to study the validity and reliability the sensors exhibit during repeated use and characterize other aspects of the system such as response times, sensor hysteresis and saturation, the effect of performing a preloading process, and determining the behaviour of the rest of the T-Scan sensitivity scales [53]. However, evidence must be interpreted with caution, since most studies are case series reports. Therefore, further studies, such as clinical trials, are recommended to confirm the computerized technology superiority over the conventional occlusal indicators.

Though clinicians may feel that operating the device may be too time-consuming and a good T-Scan recording requires a number of skills, the increased chair-time allows them to complete their objective accurately, without having to make multiple adjustments common among conventional practices [6]. Recently, digital occlusal analysis has been considered as an excellent tool to provide quantifiable time and force variances and displays accurately the occlusal contact sequence in closure in the disciplines of prosthodontics, implantology and orthodontics [54]. The introduction of a protocol for occlusal

forces measurement should be integrated in all dental disciplines and dental clinics in the future, particularly in all complex clinical cases so as to improve the precision and treatment outcome of an occlusal adjustment procedure.

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References

1. Thanathornwong B, Suebnukarn S. Clinical Decision Support Model to Predict Occlusal Force in Bruxism Patients. Healthc Inform Res. 2017; 23: 255-261.
2. Kuc J, Szarejko KD, Aleksandrowicz K, Golebiewska M. The role of soft tissue mobilization in reducing orofacial and general complaints in a patient with Kimmerle anomaly and temporomandibular joint disorder: A case report. Cranio. 2021; 39: 74-87.
3. Koos B, Godt A, Schille C, Goz G. Precision of an instrumentation-based method of analyzing occlusion and its resulting distribution of forces in the dental arch. J Orofac Orthop. 2010; 71: 403-410.
4. Lee SM, Lee JW. Computerized occlusal analysis: correlation with occlusal indexes to assess the outcome of orthodontic treatment or the severity of malocculusion. Korean J Orthod. 2016; 46: 27-35.
5. Bozhkova TP. The T-SCAN System in Evaluating Occlusal Contacts. Folia Med (Plovdiv). 2016; 58: 122-130.
6. Afrashtehfar KI, Qadeer S. Computerized occlusal analysis as an alternative occlusal indicator. Cranio. 2016; 34: 52-57.
7. Cerna M, Ferreira R, Zaror C, Navarro P, Sandoval P. *In vitro* evaluation of T-Scan® III through study of the sensels. Cranio. 2015; 33: 299-305.
8. Wang YL, Cheng J, Chen YM, Yip KH, Smales RJ, Yin XM. Patterns and forces of occlusal contacts during lateral excursions recorded by the T-Scan II system in young Chinese adults with normal occlusions. J Oral Rehabil. 2011; 38: 571-578.
9. Abdelnabi MH, Swelem AA, Al-Dharrab AA. Influence of denture adhesives on occlusion and disocclusion times. J Prosthet Dent. 2016; 115: 306-312.
10. Nassani MZ. Aspects of Malpractice in Prosthodontics. J Prosthodont. 2017; 26: 672-681.
11. Buduru S, Mesaros A, Talmaceanu D, Baru O, Ghiurca R, Cosgarea R. Occlusion in the digital era: a report on 3 cases. Med Pharm Rep. 2019; 92: S78-S84.
12. Khuder T, Yunus N, Sulaiman E, Dabbagh A. Finite element analysis and clinical complications in mandibular implant-overdentures opposing maxillary dentures. J Mech Behav Biomed Mater. 2017; 75: 97-104.
13. Khuder T, Yunus N, Sulaiman E, Ibrahim N, Khalid T, Masood M. Association between occlusal force distribution in implant overdenture prostheses and residual ridge resorption. J Oral Rehabil. 2017; 44: 398-404.
14. Akacsos SR, Kis M, Szekely M, Popsor S, Dorner K. Jaw relationship assessment for removable complete dentures using the t-scan computerised system - a case report. Med Pharm Rep. 2019; 92: S85-S90.
15. Joanna K, Teresa S, Maria G. Evaluation of functional parameters in the occlusion of complete denture wearers before and after prosthetic treatment. J Prosthodont Res. 2017; 61: 480-490.
16. Luo Q, Ding Q, Zhang L, Xie Q. Analyzing the occlusion variation of single posterior implant-supported fixed prostheses by using the T-scan system: A prospective 3-year follow-up study. J Prosthet Dent. 2020; 123: 79-84.
17. Pellicer-Chover H, Vina-Almunia J, Romero-Millan J, Penarrocha-Oltra D, Garcia-Mira B, Penarrocha-Diago M. Influence of occlusal loading on peri-implant clinical parameters. A pilot study. Med Oral Patol Oral Cir Bucal. 2014; 19: e302-307.
18. Yu W, Chen S, Li X, Ma X, Xu X. Evaluation of 1-Piece Versus 3-Piece Framework Designs for the Edentulous Mandible with Fixed Implant-Supported Prostheses: A Clinical, Occlusal and Biomechanical Study. J Prosthodont. 2021.
19. Basso MFM, Giampaolo ET, Vergani CE, Pavarina AC, Machado AL, Jorge JH. Occlusal Pressure Analysis of Complete Dentures after Microwave Disinfection: A Clinical Study. J Prosthodont. 2017; 26: 606-610.
20. Gallagher S, O'Connell BC, O'Connell AC. Assessment of occlusion after placement of stainlesssteel crowns in children - a pilot study. J Oral Rehabil. 2014; 41: 730-736.
21. Alkayyal MA, Turkistani KA, Al-Dharrab AA, Abbassy MA, Melis M, Zawawi KH. Occlusion time, occlusal balance and lateral occlusal scheme in subjects with various dental and skeletal characteristics: A prospective clinical study. J Oral Rehabil. 2020; 47: 1503-1510.
22. Qadeer S, Yang L, Sarinnaphakorn L, Kerstein RB. Comparison of closure occlusal force parameters in post-orthodontic and non-orthodontic subjects using T-Scan® III DMD occlusal analysis. Cranio. 2016; 34: 395-401.
23. Sierpinska T, Kropiwnicka A, Kuc J, Jacunski P, Golebiewska M. The influence of occlusal morphology on occlusion time. Cranio. 2017; 35: 101-109.
24. Turkistani KA, Alkayyal MA, Abbassy MA, et al. Comparison of occlusal bite force distribution in subjects with different occlusal characteristics. Cranio. 2020: 1-8.
25. Kim KY, Choi JY, Oh SH, et al. Computerized Assessment of Occlusion and Muscle Activity during Use of a Multilayer Clear Retainer: A Preliminary Study. Sensors (Basel). 2021; 21.
26. Alkan O, Kaya Y. Changes in occlusal surface area and occlusal force distribution following the wear of vacuum-formed, hawley and bonded retainers: A controlled clinical trial. J Oral Rehabil. 2020; 47: 766-774.
27. Chutchalermpan T, Pumklin J, Piyapattamin T. Evaluation of Disclusion Time in Various Angle's Malocclusions by T-Scan III System. Eur J Dent. 2019; 13: 510-513.
28. Qadeer S, Abbas AA, Sarinnaphakorn L, Kerstein RB. Comparison of excursive occlusal force parameters in post-orthodontic and non-orthodontic subjects using T-Scan® III. Cranio. 2018; 36: 11-18.
29. Uzuner FD, Odabasi H, Acar S, Tortop T, Darendeliler N. Evaluation of the effects of modified bonded rapid maxillary expansion on occlusal force distribution: A pilot study. Eur J Dent. 2016; 10: 103-108.
30. Lila-Krasniqi ZD, Shala KS, Pustina-Krasniqi T, Bicaj T, Dula LJ, Guguvcevski L. Differences between centric relation and maximum intercuspation as possible cause for development of temporomandibular disorder analyzed with T-scan III. Eur J Dent. 2015; 9: 573-579.
31. Haralur SB. Digital Evaluation of Functional Occlusion Parameters and their Association with Temporomandibular Disorders. J Clin Diagn Res. 2013; 7: 1772-1775.
32. Manfredini D, Stellini E, Marchese-Ragona R, Guarda-Nardini L. Are occlusal features associated with different temporomandibular disorder diagnoses in bruxers? Cranio. 2014; 32: 283-288.
33. Giacomo Ferrato, Giovanni Falisi, Antonella Polimeni, Carlo Di Paolo. Digital evaluation of occlusal forces: comparison between healthy subjects and TMD patients. Annali di Stomatologia. 2017; VIII: 79-88.
34. Lila-Krasniqi Z, Shala K, Krasniqi TP, et al. Differences between Subjective Balanced Occlusion and Measurements Reported With T-Scan III. Open Access Maced J Med Sci. 2017; 5: 667-672.
35. Jivnani HM, Tripathi S, Shanker R, Singh BP, Agrawal KK, Singhal R. A Study to Determine the Prevalence of Temporomandibular Disorders in a Young Adult Population and its Association with Psychological and Functional Occlusal Parameters. J Prosthodont. 2019; 28: e445-e449.
36. Leal de Godoy CH, Motta LJ, Santos Fernandes KP, Mesquita-Ferrari RA, Deana AM, Bussadori SK. Effect of low-level laser therapy on adolescents with temporomandibular disorder: a blind randomized controlled pilot study. J Oral Maxillofac Surg. 2015; 73: 622-629.

37. Agbaje JO, Casteele EV, Salem AS, et al. Assessment of occlusion with the T-Scan system in patients undergoing orthognathic surgery. Sci Rep. 2017; 7: 5356.

38. Henry BM, Pekala PA, Fraczek PA, et al. Prevalence, morphology, and morphometry of the pterygospinous bar: a meta-analysis. Surg Radiol Anat. 2020; 42: 497-507.

39. Thumati P, Kerstein RB, Thumati RP. Disclusion time reduction therapy in treating occluso-muscular pains. J Indian Prosthodont Soc. 2017; 17: 95-98.

40. Zheng S, Wu B, Zhao Y, et al. Masticatory Muscles Dysfunction after CT-guided Percutaneous Trigeminal Radiofrequency Thermocoagulation for Trigeminal Neuralgia: A Detailed Analysis. Pain Pract. 2015; 15: 712-719.

41. Liu CW, Chang YM, Shen YF, Hong HH. Using the T-scan III system to analyze occlusal function in mandibular reconstruction patients: a pilot study. Biomed J. 2015; 38: 52-57.

42. Huang YF, Liu SP, Muo CH, Chang CT. The impact of occluding pairs on the chewing patterns among the elderly. J Dent. 2020; 104: 103511.

43. Arslan H, Seckin F, Kurklu D, Karatas E, Yanikoglu N, Capar ID. The effect of various occlusal reduction levels on postoperative pain in teeth with symptomatic apical periodontitis using computerized analysis: a prospective, randomized, double-blind study. Clin Oral Investig. 2017; 21: 857-863.

44. Shin HE, Cho MJ, Amano A, Song KB, Choi YH. Association between mastication-related factors and the prevalence of dementia in Korean elderly women visiting senior centers. Gerodontology. 2020; 37: 177-184.

45. Ruttitivapanich N, Tansalarak R, Palasuk J, Pumklin J. Correlation of Bite Force Interpretation in Maximal Intercuspal Position among Patient, Clinician, and T-Scan III System. Eur J Dent. 2019; 13: 330-334.

46. Silva PF, Motta LJ, Silva SM, Ferrari RA, Fernandes KP, Bussadori SK. Computerized analysis of the distribution of occlusal contacts in individuals with Parkinson's disease and temporomandibular disorder. Cranio. 2016; 34: 358-362.

47. Gumus HO, Kilinc HI, Tuna SH, Ozcan N. Computerized analysis of occlusal contacts in bruxism patients treated with occlusal splint therapy. J Adv Prosthodont. 2013; 5: 256-261.

48. Di Berardino F, Filipponi E, Schiappadori M, Forti S, Zanetti D, Cesarani A. The occlusal imaging and analysis system by T-scan III in tinnitus patients. Biomed J. 2016; 39: 139-144.

49. Wang XR, Zhang Y, Xing N, Xu YF, Wang MQ. Stable tooth contacts in intercuspal occlusion makes for utilities of the jaw elevators during maximal voluntary clenching. J Oral Rehabil. 2013; 40: 319-328.

50. Wieczorek A, Loster J, Loster BW. Relationship between occlusal force distribution and the activity of masseter and anterior temporalis muscles in asymptomatic young adults. Biomed Res Int. 2013; 2013: 354017.

51. Sutter B, Yiannios N, Radke J. Letter to the Editor regarding. "*In vitro* evaluation of T-Scan® III through study of the sensels" from CRANIO, by Manuel Cerna et al. Cranio. 2016; 34: 208-209.

52. Baldini A, Nota A, Cozza P. The association between Occlusion Time and Temporomandibular Disorders. J Electromyogr Kinesiol. 2015; 25: 151-154.

53. Cerna M, Ferreira R, Zaror C, Navarro P, Sandoval P. Validity and reliability of the T-Scan® III for measuring force under laboratory conditions. J Oral Rehabil. 2015; 42: 544-551.

54. Trpevska V, Kovacevska G, Benedeti A, Jordanov B. T-scan III system diagnostic tool for digital occlusal analysis in orthodontics - a modern approach. Pril (Makedon Akad Nauk Umet Odd Med Nauki). 2014; 35: 155-160.