

Original Paper

Relationship Between the Applied Occlusal Load and the Size of Markings Produced Due to Occlusal Contact Using Dental Articulating Paper and T-Scan: Comparative Study

Shravya Reddy*, BDS, MDS; Preeti S Kumar*, BDS, MDS; Vyoma V Grandhi*, BDS, MDS

Department of Prosthodontics, The Oxford Dental College, Bangalore, India

* all authors contributed equally

Corresponding Author:

Preeti S Kumar, BDS, MDS

Department of Prosthodontics

The Oxford Dental College

10th Mile Stone, Hosur Road, Bommanahalli

Bangalore, 560065

India

Phone: 91 9845493230

Email: drpreetisatheesh@gmail.com

Abstract

Background: The proposed experimental design was devised to determine whether a relationship exists between the occlusal load applied and the size of the markings produced from tooth contact when dental articulating paper and T-Scan are interposed alternatively.

Objective: The objective of our study was to compare the relationship between contact markings on an articulating paper and T-Scan for an applied occlusal load.

Methods: In this in vitro study, dentulous maxillary and mandibular dies were mounted on a metal jig and articulating paper and T-Scan sensor were placed alternatively between the casts. Loads simulating occlusal loads began at 25 N and incrementally continued up to 450 N. The resultant markings (180 marks resulting from articulating paper and 138 from T-Scan) were photographed, and the marks were analyzed using MOTIC image analysis and sketching software. Descriptive statistical analyses were performed using one-way analysis of variance, Student *t* test, and Pearson correlation coefficient method.

Results: Statistical interpretation of the data indicated that with articulating paper, the mark area increased nonlinearly with increasing load and there was a false-positive result. The characteristics of the paper mark appearance did not describe the amount of occlusal load present on a given tooth. The contact marking obtained using T-Scan for an applied occlusal load indicated that the mark area increased with increase in the load and provided more predictable results of actual load content within the occlusal contact.

Conclusions: The size of an articulating paper mark may not be a reliable predictor of the actual load content within the occlusal contact, whereas a T-Scan provides more predictable results of the actual load content within the occlusal contact.

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KEYWORDS

occlusal indicator; occlusal load; articulating paper; T-Scan

Introduction

Over the years, occlusal analysis has been a matter of guesswork. Occlusal indicators are widely used in dental treatment to measure tooth contacts that occur during occlusion. They are important tools in locating interference and refining occlusal contacts during prosthodontic rehabilitation [1]. Aids

such as articulating paper, waxes, and pressure-indicating paste are used when a dentist has to assess and balance the occlusal forces. The accurate measurement of tooth contacts can provide valuable information for diagnostic, treatment, or prognostic purposes. Hence, the accuracy of these indicators is essential for the establishment of occlusal harmony [2].

Occlusal indicators can be broadly divided into two categories based on their measurement capacity: qualitative and quantitative indicators. Qualitative indicators, such as the articulating paper and articulating silk, are limited in measurement to only the location and number of tooth contacts [1]; these are the most commonly used indicators because of their low cost and ease of application. Quantitative indicators, on the other hand, include electro-optic and resistive techniques such as the T-Scan pressure measurement system; these indicators have the added capability of measuring the time and force characteristics of tooth contacts, but they are more expensive [1].

It has been advocated in textbooks on occlusion [3-8] that the articulating paper mark area is a representative of the load contained within the mark. While using the articulating paper, we tend to assume that a vivid occlusal contact is the location where a large occlusal force has been applied [9]. The articulating paper mark appearance describes that large and dark marks indicate heavy load, whereas smaller and light marks indicate lightloads. Additionally, the presence of many similar-sized marks spread around the contacting arches is purported to indicate the equal occlusal contact intensity, evenness, and simultaneity [10]. However, limited literature exists to clinically correlate and confirm these findings. By employing articulating paper as a force measurement device, we, as clinicians, miss properly seeing the occlusal force, occlusal contact intensity, evenness, and simultaneity [9]. Hence, this proposed experimental design was devised to determine whether a relationship exists between the applied occlusal load and the size of the markings produced from the tooth contact when a clinically used dental articulating paper and T-scan are interposed alternatively.

Methods

Materials Used

We used Bausch 40- μ m microthin articulating papers and ultrathin T-Scan III sensor (.004 inch, 0.1 mm). The articulating

paper was tear resistant and coated with liquid colors on both sides. The special color coating with liquid colors consists of many color-filled microcapsules. Even the slightest masticatory pressure can cause the capsules to burst and, thus, release the distinctly visible color. The T-Scan system comprises a sensor, handle and cable, system unit, and software that detect patients' occlusal forces. The handle's attached USB cable is then connected directly to the computer via the USB port.

Mounting of Metal Dies and Contact Procedure

Using articulating paper mark, occlusal loads were evaluated on a solid metal die (Figure 1) with no soft-tissue components. Vertical loading was accomplished by designing a cast anchoring apparatus that attached the metal dies to a metal jig. The metal dies were secured to the metal jig through machined rods with alignment holes (Figure 2) that ensured a precise alignment of the maxillary and mandibular casts prior to testing. The recording materials—articulating paper and T-Scan III—were placed sequentially on the occlusal surface of the mandibular teeth of the model.

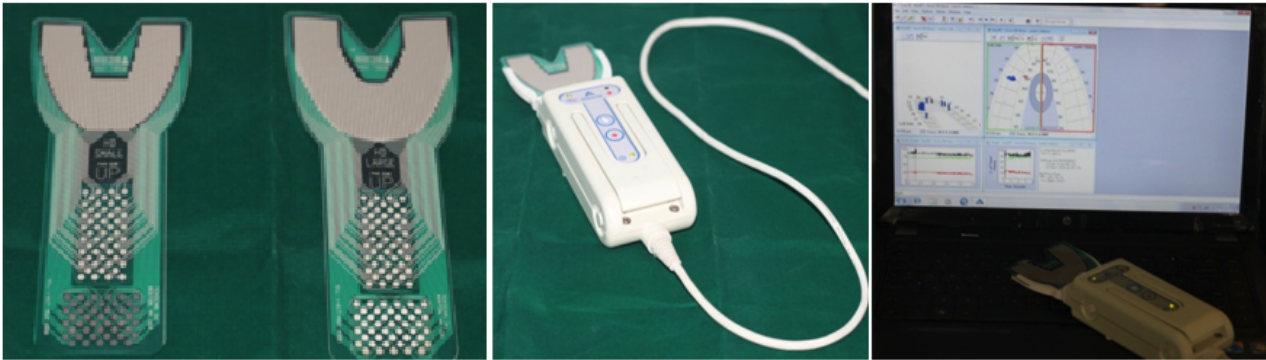
Methodology

Preliminary loading of casts was performed once to properly mate the casts and then again to ensure that the overshoot of load cell was an acceptable value. Then, the Bausch articulating paper (thickness, 0.04 mm), with red surface occluding the maxillary cast and blue surface occluding the mandibular cast, was held in place between the casts. The loading began before the dies were intercusped until complete intercuspidation at 25-N loads. Then, the readings on the displaying unit were recorded before returning to zero position to release the load. This procedure was repeated 2 more times, with each 3-tap trial comprising one test. Next, the paper markings left on the maxillary and mandibular casts were photographed with a 10-megapixel digital camera. The load was gradually increased from 25 N to 450 N, and the entire process was repeated.

Figure 1. Horseshoe-shaped, full arch, red-blue articulating paper (left) and articulating paper mark area (right).



Figure 2. Metal maxillary and mandibular dies mounted on a jig.



Recording Procedure Using T-Scan III

Prior to recording, the handle with a sensor (Figure 3) and arch support was placed between the maxillary and mandibular metal dies. The sensor was placed in such a way that it aligned centrally with the midline of the maxillary incisors. Then, the recording was initiated by depressing and releasing the recording button located on the top surface of the recording handle. After the handle button was pressed, the arch model was automatically created on the screen. When the sensor was placed between the two opposing dies at maximum intercuspation, the resultant reduction in electric resistance was translated into an image on the screen (Figure 4). We used MOTIC software (Motic microscopy, Hong Kong; accessed from the Department of Oral Pathology, The Oxford Dental College Bangalore), which has been designed to analyze and display tooth contact data as registered by the sensor (Figure 5). Next, the T-scan III was occluded between the metal dies and the force was loaded and recorded. The load was gradually increased from 25 N to 450 N, and the entire process was repeated. This procedure was repeated 2 more times, with each 3-tap trial comprising one test [11].

Image Analysis and Processing

Photographs of the paper markings left on the maxillary and mandibular casts resulting from each 3-tap trial were analyzed. We used a 10-mega pixel digital camera placed at a distance of 6 inches from the metal dies. The experimental design produced 100 photos for analysis. In all photographs, 6 prominent markings (indicating 6 contacts) were identified on the casts.

Any other inconsistent occlusal markings were disregarded. The 6 distinct contact markings were analyzed using MOTIC software to magnify the markings. The markings were analyzed sequentially from contact numbers 1-6. A total of 180 (6 teeth \times 10 force levels \times 3 repetitions = 180) marks were statistically analyzed. Furthermore, the photographs of T-Scan markings, which were displayed as an arch model on the screen, were analyzed using MOTIC software.

Calculation of the Size of the Largest Paper Mark per Photograph

We used a freehand sketcher (Adobe Photoshop CS4, San Jose, CA, USA) to magnify and calculate the paper mark surface area in photographic pixels of the largest and most prominent articulation paper mark found in a marked quadrant. MOTIC software was used to magnify the markings so that the freehand sketcher could be used to trace the boundary of the paper mark. The largest mark was outlined using MOTIC software outline sketcher command, which accessed the number of pixel count within the enclosed boundary (the freehand sketcher automatically calculates the number of pixels enclosed within the outlined area). Next, the tooth and the contact location of the largest paper mark in a quadrant were recorded in a spreadsheet for future data analysis.

Statistical Analysis

We performed descriptive statistical analysis in this study. Comparisons were performed using one-way analysis of variance (ANOVA), Student *t* test, and Pearson correlation coefficient method.

Figure 3. T-Scan sensor, USB handle with attached USB cable, and T-Scan system unit.



Figure 4. T-Scan contact markings.



Figure 5. Image analysis using MOTIC software.



Results

Data were plotted for each of the 6 marks of the articulating paper and the marks that were evaluated using T-Scan. We plotted a best-fit curve and performed one-way ANOVA and Pearson correlation coefficient method. Data were grouped and plotted by each load level to calculate descriptive statistics. Because all teeth were subjected to the exactly same loads, Student *t* test was used to determine whether the mark areas

were the same or significantly different at each load. During all tests, no gross observable paper failure was found; however, some local indentations or crinkling was observed as paper conformed to the shape of tooth edges. Furthermore, each T-Scan sensor was used for 10 test loads.

In the incisor region, the articulating paper mark area was maximum at a load of 300 N and was 282.50 μm^2 , whereas with the T-Scan, the maximum area was 30.63 μm^2 at 100 N (Tables 1 and 2; Figure 6).

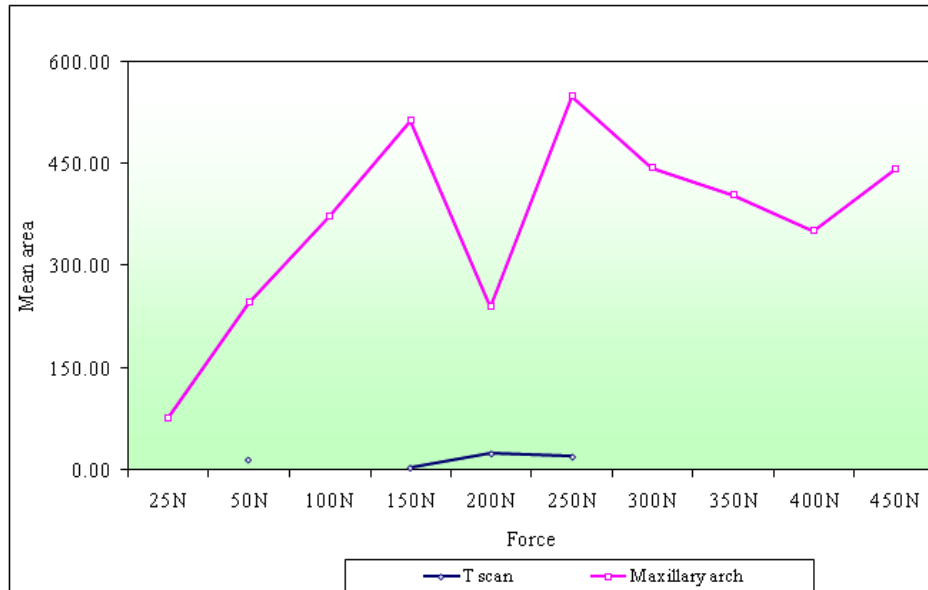
Table 1. Comparison of different forces with area (in micrometer square) marked with articulating paper in different teeth regions using one-way analysis of variance.

Force (N)	Left side canine, mean (SD)	Incisors, mean (SD)	Right side canine, mean (SD)	Premolar, mean (SD)	First molar, mean (SD)	Second molar, mean (SD)
25	58.00 (16.52)	46.67 (10.12)	36.00 (3.46)	75.67 (30.92)	50.17 (11.09)	37.33 (6.43)
50	55.67 (4.91)0	166.50 (48.48)	33.17 (7.94)	247.00 (26.51)	170.67 (48.91)	137.67 (27.32)
100	101.50 (8.67)	166.67 (36.94)	48.33 (21.94)	373.67 (86.77)	251.67 (55.99)	131.33 (29.26)
150	35.00 (7.94)	171.67 (32.52)	69.00 (3.46)	513.33 (69.95)	202.33 (59.47)	184.00 (11.27)
200	113.50 (16.86)	208.67 (7.51)	130.33 (30.14)	239.33 (44.46)	239.33 (44.46)	160.00 (21.28)
250	105.17 (8.95)	242.67 (29.87)	94.33 (20.31)	549.67 (32.75)	271.00 (20.22)	243.00 (29.55)
300	98.17 (15.25)	282.50 (78.38)	103.67 (10.50)	444.67 (34.20)	269.50 (62.93)	213.33 (25.11)
350	77.50 (10.76)	251.00 (89.00)	82.67 (1.53)	404.67 (60.05)	256.00 (42.79)	265.33 (15.70)
400	85.00 (11.95)	140.17 (28.65)	68.00 (8.72)	350.83 (35.76)	166.83 (41.12)	128.33 (22.81)
450	99.00 (7.76)	178.00 (36.37)	79.33 (6.03)	442.33 (37.87)	159.67 (28.22)	169.00 (43.14)
<i>P</i> value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 2. Comparison of different forces with area (in micrometer square) marked with T-Scan in different teeth regions using analysis of variance.

Force (N)	Left side					Right side				
	Second molar, mean (SD)	First molar, mean (SD)	Premolar, mean (SD)	Canine, mean (SD)	Incisors, mean (SD)	Incisors, mean (SD)	Canine, mean (SD)	Premolar, mean (SD)	First molar, mean (SD)	
25	N/A ^a	N/A	N/A	10.90 (1.00)	10.40 (0.72)	N/A	N/A	N/A	N/A	
50	N/A	N/A	15.37 (8.00)	3.03 (0.81)	2.47 (0.32)	N/A	N/A	N/A	N/A	
100	N/A	21.00 (1.00)	N/A	N/A	30.63 (3.50)	N/A	N/A	N/A	N/A	
150	N/A	13.47 (4.97)	3.60 (1.41)	2.67 (1.10)	21.33 (4.93)	N/A	N/A	N/A	N/A	
200	N/A	20.33 (8.33)	21.67 (4.04)	15.33 (3.21)	N/A	6.00 (3.00)	2.23 (0.68)	2.70 (1.47)	N/A	
250	N/A	30.20 (6.88)	19.67 (7.64)	7.50 (1.87)	N/A	24.67 (7.19)	N/A	N/A	N/A	
300	N/A	15.53 (0.55)	21.97 (4.38)	38.70 (2.04)	21.90 (5.12)	N/A	N/A	2.87 (1.36)	N/A	
350	8.30 (8.44)	20.63 (5.12)	16.10 (2.95)	N/A	N/A	N/A	4.20 (0.95)	N/A	N/A	
400	17.73 (1.00)	41.33 (4.51)	37.67 (7.77)	37.67 (11.68)	21.67 (5.03)	N/A	24.67 (6.81)	13.10 (1.65)	28.60 (2.62)	
450	19.30 (5.52)	49.97 (6.41)	56.37 (7.42)	52.87 (12.27)	27.73 (3.66)	N/A	11.10 (3.92)	30.53 (2.38)	31.83 (1.60)	

^aN/A: not applicable.

Figure 6. Comparison between results with articulating paper and T-Scan for applied load in the incisor region.**Figure 7.** Comparison between results with articulating paper and T-Scan for applied load in the canine region.

The size of the mark area was approximately 9 times greater with the articulating paper than with the T-Scan. In the canine region (Tables 1 and 2; Figure 7), the articulating paper mark area was maximum at 200 N and was $130.33 \mu\text{m}^2$, whereas with the T-Scan, the maximum area was $52.87 \mu\text{m}^2$ at 450 N. The mark area with the articulating paper was approximately 2 times greater than that with the T-Scan. In the premolar region (Tables 1 and 2; Figure 8), the articulating paper mark area was maximum at 250N and was $549.67 \mu\text{m}^2$, whereas with the T-Scan, the maximum area was $56.37 \mu\text{m}^2$ at 450 N. The mark area with the articulating paper was approximately 9 times

greater than that with the T-Scan. In the first molar region (Tables 1 and 2; Figure 9), the articulating paper mark area was maximum at 250 N and was $271 \mu\text{m}^2$, whereas with the T-Scan, the maximum area was $49.97 \mu\text{m}^2$ at 450 N. The mark area with the articulating paper was approximately 5 times greater than that with the T-Scan. In the second molar region (Tables 1 and 2; Figure 10), the articulating paper mark area was maximum at 350 N and was $265.33 \mu\text{m}^2$, whereas with T-Scan, the maximum area was $19.30 \mu\text{m}^2$ at 450 N. The mark area with the articulating paper was approximately 10 times greater than that with the T-Scan.

Figure 8. Comparison between results with articulating paper and T-Scan for applied load in the first premolar region.

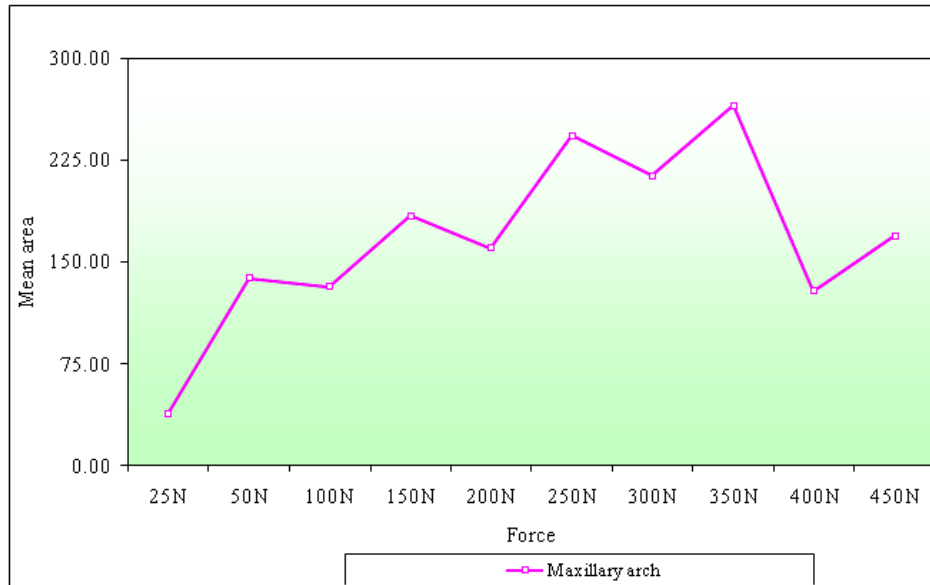


Figure 9. Comparison between results with articulating paper and T-Scan for applied load in the first molar region.

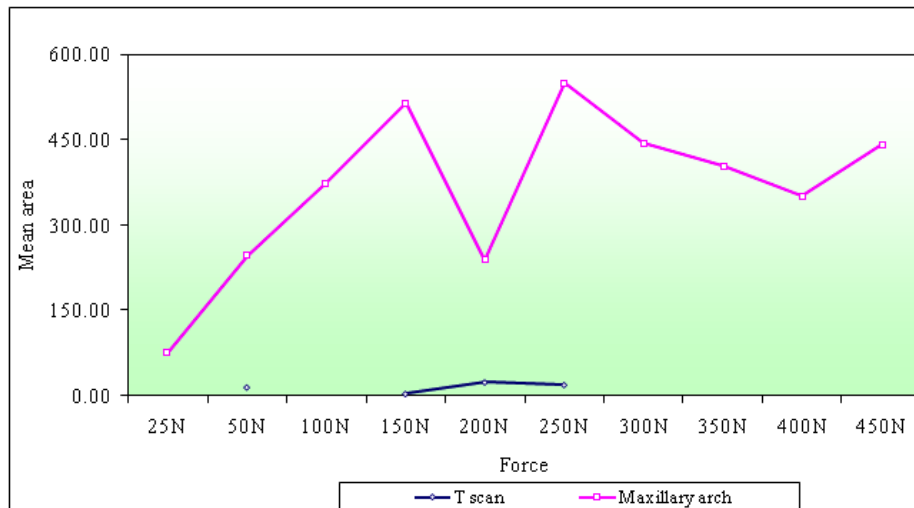
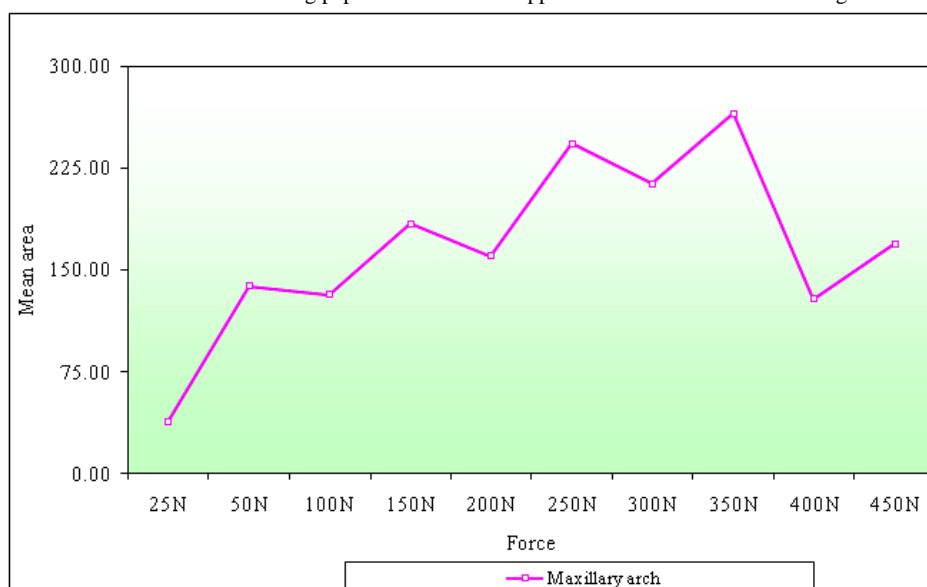


Figure 10. Comparison between results with articulating paper and T-Scan for applied load in the second molar region.



Figure 11. Comparison between results with articulating paper and T-Scan for applied load in the first molar region.**Figure 12.** Comparison between results with articulating paper and T-Scan for applied load in the second molar region.

Discussion

Principal Findings

Articulating papers are the most frequently used qualitative indicators to locate the occlusal contacts intraorally; their basic constituents are a coloring agent and a bonding agent between the two layers of the film [10]. On occlusal contact, the coloring agent is expelled from the film, and the bonding agent binds it on to the tooth surface [12]. On heavy contacts (ie, greatest masticatory pressure), more color is squeezed out, resulting in dark marks. When light contacts are made (ie, slight masticatory pressure), less color is expelled, resulting in light marks. On heavy contacts (ie, greatest masticatory pressure), more color is squeezed out, resulting in dark marks. When light contacts are made (ie, slight masticatory pressure), less color is expelled, resulting in light marks. The selected marks to adjust are generally chosen on the basis of their appearance characteristics. The characteristic marking is observed as a central area that is devoid of the colorant and surrounded by a peripheral rim of the dye; this region is called “target” or “iris” owing to its

appearance, and it denotes the exact contact point. The density of these markings does not denote the force of the contact; instead, heavier contacts tend to spread the mark peripheral to the actual location of the occlusal contact. Only the central portion in heavy contact areas indicates the interference that requires correction [12]. We evaluated this hypothesis to determine whether a relationship exists between the applied occlusal load and the size of the markings produced from tooth contact when a clinically used dental articulating paper and T-Scan are interposed alternatively.

The results of this study suggest that there is no correlation between the mark area and the applied occlusal load. With the articulating paper, we observed false-positive results, which is in accordance with the results of a study conducted by Kerstein and Qadeer [13,14] who attempted to correlate the occlusal force to the paper mark size. Hence, we can conclude that the characteristics of the paper mark appearance do not describe the amount of occlusal load present on a given tooth. In addition, this study proved that the incremental load increase did not result in an equal increase in mark area size on any individual

contact; furthermore, the maximum area recorded was at the maximum force with T-Scan, which is in accordance with Carey et al [10], Kim [9], Reza and Neff [15], and Garrido et al [16]. This computerized occlusal analysis showed that similar-sized and widely distributed marks did not indicate a measurably simultaneous occlusal scheme; furthermore, despite their similar sizes, those same marks exhibited a wide range of forces.

Afrashtehfar and Qadeer [17] have reported that the computerized occlusal analysis system provides quantifiable force and time variance in a real-time window from the initial tooth contact to the maximum intercuspatation, therefore, providing valuable information. Bozhkova [18] reported that the T-Scan system provides a very accurate way of determining and evaluating the time sequence and force magnitude of occlusal contacts by converting qualitative data into quantitative parameters and displaying them digitally. The system is a useful clinical method that eliminates a biased, subjective evaluation of the occlusal and articulating relations on the part of an operator, which is in accordance with the results of our study [18].

An assumption made regarding the articulating paper labeling is that the size and color intensity describe forceful contact. A broad, dark-colored contact is perceived as a forceful contact. A possible explanation for this relationship between the size of the contact and its force content is that the applied pressure of the occlusal force is measured relative to its surface area as follows: pressure applied force/surface area

Broad contacts dissipate force over a large area, resulting in low-pressure concentration, whereas a small contact will dissipate the occlusal force over a small area. Thus, the smaller the surface area that receives a given force, the more the pressure. A computerized analysis may reveal that dentists have been misreading the size of the articulating paper labeling by reading it inversely. Therefore, large or broad contacts are representative of low pressure, while small contacts represent high pressure. The only data that appear to be obtainable with articulating paper labeling are occlusal contact location and surface area. In addition, color intensity, size of labeling, and microscratch labeling reveal the presence of an occlusal contact

without revealing any description of the force content or time sequence data.

Limitations

Only one type of commonly used articulating paper was used in this study; thus, extrapolations of the behavior of other paper or ribbon types cannot be universally made. The results do not necessarily reflect other types and thicknesses of different commercially available articulating papers. Articulating paper is very delicate and tends to smudge even with finger pressure, giving false-positive markings. In this study, the complexities of the anatomical and physiological aspects of the human teeth, which rest in the hydrodynamic environment of the periodontal ligament, were purposefully not duplicated. The final limitation was subjectively defining and sketching the boundary of the mark area using MOTIC software; it was easier to identify the boundaries of the blue markings than those of the red markings.

Conclusion

In this bench analysis, we could not find a linear relationship between the applied load and the articulating paper mark area because of the high degree of mark area variability observed at each test load across differing teeth and contacts. These findings question the long-standing dental premises that the size of an articulating paper mark indicates its load content. Contact marking using T-Scan for an applied occlusal load helped conclude that the mark area increased with an increase in the load.

From the results of this study, we can conclude that the combination of these two different mediums can guide the occlusal adjustment procedure to result in a measurable bilateral simultaneous occlusal contact sequence. Furthermore, the size of an articulating paper mark may not be a reliable predictor of the actual load content within the occlusal contact, and T-Scan gives more predictable results of the actual load content within the occlusal contact. Hence, it is imperative that dentists realize that the articulating paper mark size is subject to interpretation and could be an unreliable method to use for occlusal equilibration

Conflicts of Interest

None declared.

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Abbreviations

ANOVA: analysis of variance

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