Occlusion

Clinician accuracy when subjectively interpreting articulating paper markings

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Aims: The aim of this study was to determine whether *Subjective Interpretation* of paper markings is a reliable method for identifying the relative occlusal force content of tooth contacts.

Methodology: 295 clinicians selected the "Most Forceful" and "Least Forceful" occlusal contacts in six occlusal-view photographs of articulating paper marks that were later compared against computerized occlusal analysis relative occlusal force measurements of the same tooth contacts. Means and standard deviations were calculated by *years in clinical practice* and by *number of occlusion courses taken*. A Chi-square analysis was also performed.

Results: The mean correct for 295 participant dentists was 1.53 (±1.234). There were no significant differences found for years in practice ($P>0.16$) or number of occlusion courses taken ($P>0.75$). The Chi-square analysis showed a sensitivity of 12.6%, a specificity of 12.4%, a positive predictive value of 12.58%, and a negative predictive value of 12.42%. Chance was calculated at 12.5% correct.

Conclusions: Subjective Interpretation is an ineffective clinical method for determining the relative occlusal force content of tooth contacts. The reported low scores obtained from a large group of participant dentists suggest clinicians are unable to reliably differentiate high and low occlusal force from looking at articulating paper marks. This longstanding method of visually observing articulating paper marks for occlusal contact force content should be replaced with a measurement-based, objective method.

Keywords: Applied occlusal load, Articulating paper mark size, Computerized occlusal analysis system, Least forceful, Most forceful, Subjective Interpretation of paper marks

Introduction

Subjective Interpretation of articulating paper markings is the most commonly employed method that clinicians use to select tooth contacts for occlusal treatment. No study data has been published that illustrates that clinicians can accurately determine tooth contact relative occlusal force content using "Subjective Interpretation" of articulating paper markings. This technique is based upon the premise that articulating paper mark appearance characteristics illustrate the occlusal contact force content. However, no studies substantiate the premise that articulating paper mark size, color intensity, or shape, accurately represents applied occlusal load. Despite the lack of scientific evidence supporting the use of *Subjective Interpretation*, it has been a longstanding, well-accepted method, by which clinicians supposedly can determine the relative occlusal force content of occlusal contacts.

Articulating paper is used to identify contact points between the maxillary and mandibular teeth. Occlusal adjustments are made by selectively grinding the paper marks to obtain occlusal stability,[1] to establish multiple contacts throughout the arches that exhibit simultaneity,[2] and to reduce stresses on teeth and the periodontium.[3] The selected marks to adjust are generally chosen based upon their appearance. To aid in the determination of which teeth and contact(s) require adjustment, use of Shim stock strips has been advocated for use in combination with articulating paper.[4] But because Shim stock does not mark the involved teeth, the articulating paper mark appearance is *Subjectively Interpreted* to choose contacts that appear to require occlusal treatment.

It has been advocated in textbooks on 'Occlusion'[1–3,5–7] that mark size is representative of the load contained within the mark. Legends to photographs depicting occlusal adjustment technique

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describe that large dark marks indicate heavy load, and that smaller light marks indicate lesser loads.[5–7] Additionally, the presence of many similar sized marks spread around the contacting arches is purported to indicate equal occlusal contact intensity, evenness, and simultaneity.[1,3,4–7] These core principles of paper mark appearance are to act as a ''guide'' for clinicians to employ during the process of *subjectively interpreting* tooth contacts for their relative occlusal force content.

Published studies about articulation paper are analyses of physical properties of the marking strips (thickness, composition, ink substrate, plastic deformation), and do not detail that articulating paper can measure relative occlusal force.[8–10] Studies analyzing whether paper mark size characteristics are representative of applied occlusal load consistently indicate that there is no correlation between the size of articulating paper markings and applied occlusal load.[11–13] In 2007, Carey *et al.*[11] analyzed 600 paper markings made by loading articulated epoxy casts with incrementally increasing occlusal loads (between 0 and 500 N). The authors reported a high variability of mark sizes was associated with each test load, showing that numerous mark sizes were representative of a single load. They also demonstrated that an incremental load increase did not result in an equal mark area size increase on any individual tooth. Instead, they observed that under higher loads, sometimes the articulating paper mark areas decreased in size. Lastly, they reported a 21% agreement between applied load and mark size, indicating a low probability that similar sized marks will demonstrate equal loads. Their results indicated that relative mark size could not be used reliably to measure relative occlusal force.[11]

In 2008, Saad *et al.*[12] tested both articulating paper marking reliability and occlusal force description capability by using two different thicknesses of articulating papers (23 and 60 μm thick) that were interposed between articulated ivorine casts while being occluded by a load cell at three different loads (150, 200, and 250 N). The authors reported that more and larger marks were obtained with the thicker paper, and that mark size did not change appreciably with an increase in the applied load. They also noted that the clinician is required to use ''acumen'' to *subjectively interpret* the marks and distinguish false positives from true occlusal contact.[12]

In 2012, Quadeer *et al.*[13] required 30 dentate female subjects to self-intercuspate thru articulation paper strips to mark maxillary posterior occlusal contacts. Two hundred and forty paper markings were photographed and compared to the same subject's computerized occlusal analysis force percentage per tooth (force %/tooth) measurements of the same intercuspated teeth. The surface area of the largest articulation paper mark in each quadrant (calculated in photographic pixels), was matched with the computer-measured force percentage present on that same tooth, to determine how frequently the largest paper mark was located on the tooth with the greatest force percentage. The authors reported that the largest paper mark was matched with the most forceful tooth only 38.3% of the time, and that only 6.4% of mark surface area was created by applied force,[10] because 93.6% of the mark area resulted from other factors unrelated to force (occlusal surface topography; surface wetness/dryness). They wrote ''choosing forceful tooth contacts utilizing paper mark appearance as a guide is at best, not evidence-based, and at worst, highly error-prone. With the largest mark indicating the most forceful tooth only 38% of the time, a dentist would be choosing the wrong tooth incorrectly at least 62% of the time.''[13]

Computerized occlusal analysis technology was first introduced in the mid-1980s.[14] Its hardware, software, and recording sensors have all been evolved by the manufacturer, into a chair-side occlusal diagnostic and treatment clinical adjunct.[15–17] The T-Scan III system's recording High-definition Generation IV sensor, (Tekscan Inc., South Boston, MA, USA) has been shown to be capable of repeatedly measuring relative occlusal force.[18] The sensor is an electronically-charged, Mylar-encased recording thin-film sensor, which can acquire 256 levels of occlusal contact relative force as a patient intercuspates, or makes excursive movements across its recording surface.[15–17] The sensor's electronic *Digital Output* is proportional to the applied occlusal load at each contact point, is color-coded for its relative occlusal force content, and is positioned within a dental arch by where on the sensor surface occlusal contact occurs. The software processes and displays the occlusal force data of recorded occlusal events in two and three dimensions to be used in the diagnosis and treatment of occlusal force excess.[16]

The specific aims of this investigation were: (1) to test the clinical competence of dentists using *Subjective Interpretation* of articulating paper markings when identifying the relative occlusal force content of occlusal contacts, and (2) to determine whether Subjective Interpretation of articulating paper markings is a reliable method for clinicians to employ when determining occlusal contact relative force content. This is the first attempted, clinician

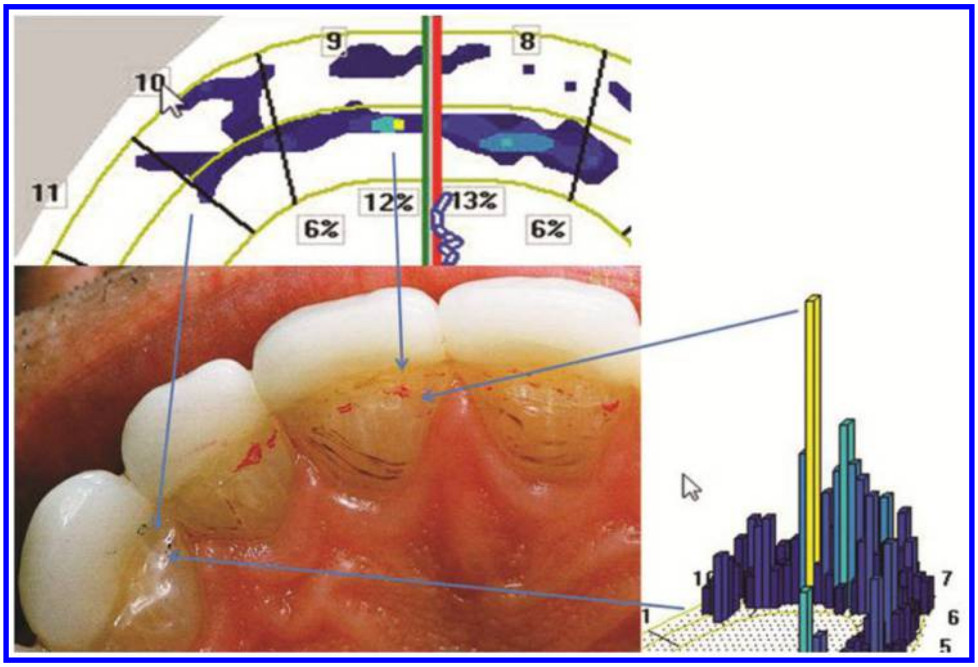

Figure 1 Maxillary anterior lingual articulating paper markings with computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

diagnostic challenge study, comparing the accuracy of dentist-perceived forceful and non-forceful occlusal contacts to actual relative occlusal contact force measurement data. The study examined how well a large group of clinicians could observe multiple neighboring articulating paper marks and reliably select occlusal contact force content.

Materials and Methods

Two hundred and ninety-five practicing dentists of varying years of experience (0–20+ years), and differing levels of occlusal education (0–7+ occlusion continuing education courses taken) were asked verbally for their permission to participate in an articulating paper mark evaluation study. Potential participants were informed that they would be taking a ''picture observation'' test. Those who consented to participate in the study agreed to take the test. Those who did not give their consent did not take the test. Consenting dentists observed six colored photographs of articulating paper markings made upon small groupings of maxillary teeth. Additionally,

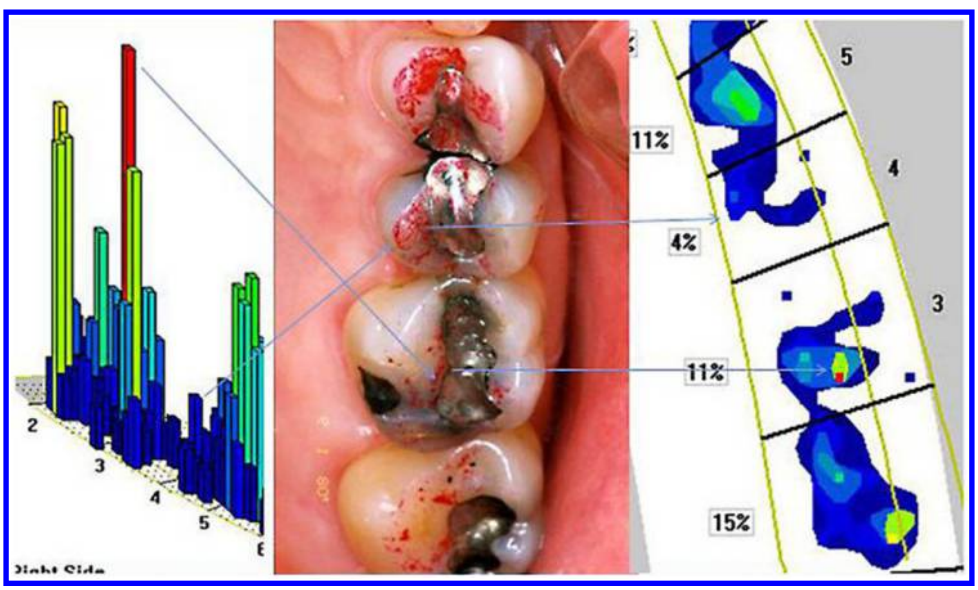

Figure 2 Maxillary right posterior articulating paper markings with computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

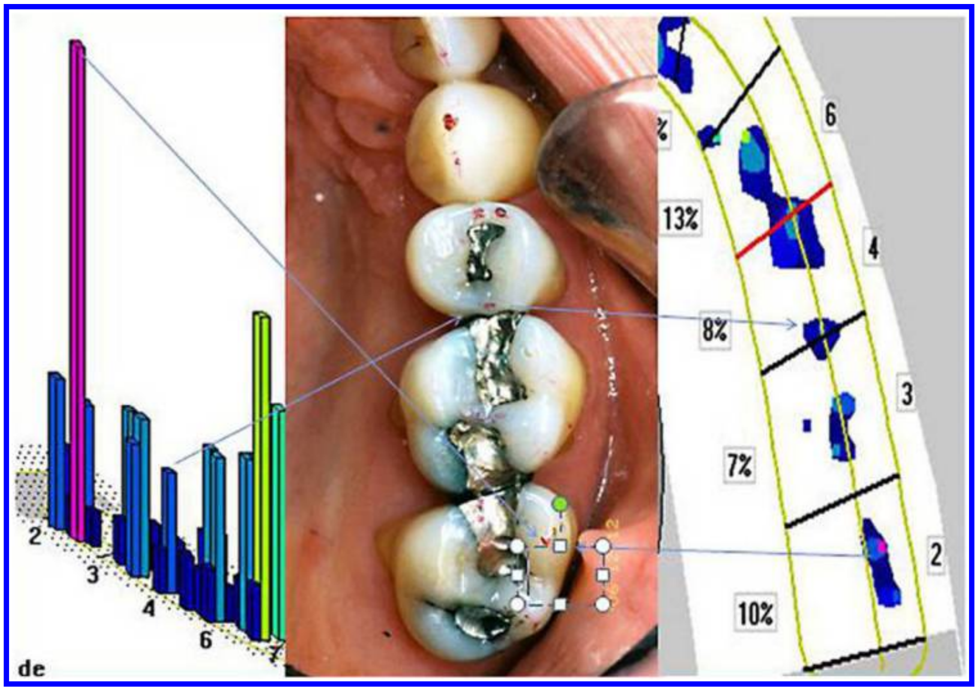

Figure 3 Alternate maxillary right posterior articulating paper markings with computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

verbal permission was obtained from the six patients to photograph their teeth before photographing the teeth that comprised the "test." No patient facial photos were taken and none were included in the study. The study protocol was assessed by the Solutions Institutional Review Board, which determined the proposed research protocol was in compliance with the OHRP's Regulations for the Protection of Human Subjects (45 CFR 46), and has been classified as exempt; category 1–4.

The clinical photographs shown in Figs. 1–6 were presented to the participants, without the companion-computerized answer data. The participants were asked to identify the single *most forceful*, and the single *least forceful* contact present in each photograph by employing Subjective Interpretation in the same way they utilized Subjective Interpretation in clinical practice. The participants were instructed that there were only two correct answer contacts per photograph, such that they

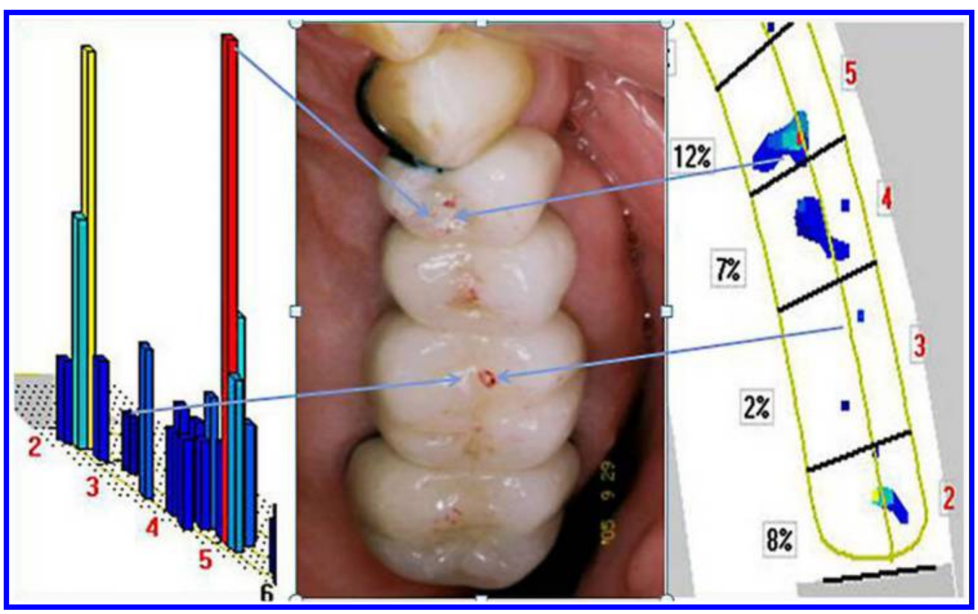

Figure 4 Maxillary right posterior fixed bridge with articulating paper markings and computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

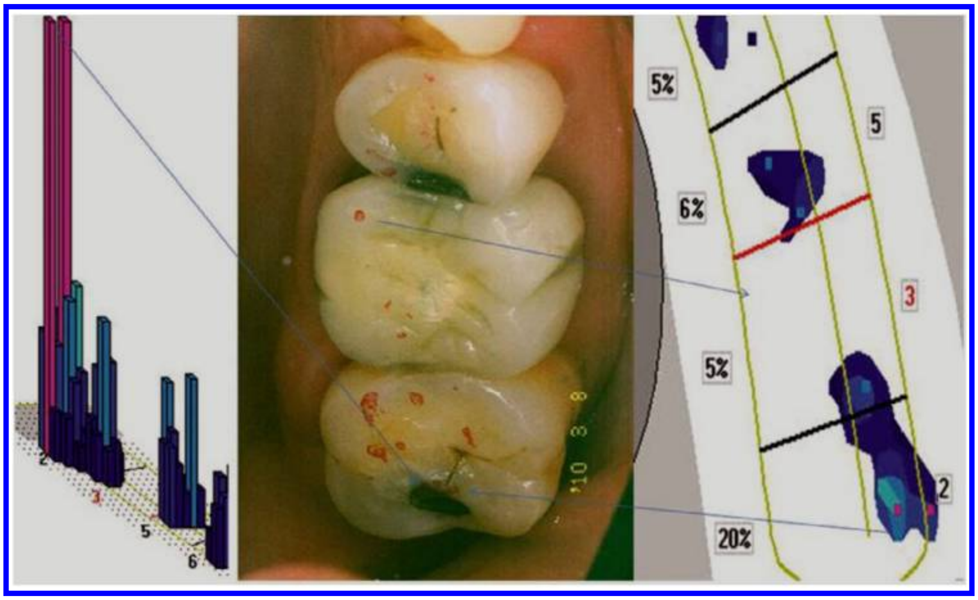

Figure 5 Maxillary right posterior articulating paper markings with computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

should report on only two contacts per photograph (one most forceful contact; one least forceful contact).

Paper marking/photographic procedure

During the ongoing practice of prosthodontics involving computer-guided occlusal adjustment procedures, a single operator selected partial regions of the maxilla from six different patients, to be marked during repeated patient self-intercuspations with 23 micron thick articulating marking strips (Accufilm, Parkell, Inc., Farmingdale, NY, USA), which has been shown to create the least number of false-positive occlusal contact markings.[9] The markings were created by air-drying the selected teeth, after which the patients repeatedly self-closed through a single marking strip. No excursive movement paper mark patterns were included in the test. The resultant colored markings were photographed off a mirror using a digital SLR camera with aperture F32 and shutter speed of 2/5 second (Nikon D3100; Nikon Inc., Melville, NY, USA).

After a clinical photograph was obtained, where all markings were easily discernible, the same patient underwent a *Multi-bite* computerized occlusal analysis force recording,[13,16] which measured the relative occlusal force content of the occlusal contacts present on the photographed teeth. The Multi-bite playback

Figure 6 Maxillary right canine and premolar posterior articulating paper markings with computerized occlusal analysis relative force profile. Arrows denote most and least forceful contacts.

was saved to later compare the paper-mark photographs to the measured relative occlusal force profile of the marked teeth. All six photographs were downloaded to a PC, and pasted digitally into a document (Microsoft Word 2003; Microsoft Inc., Seattle, WA, USA) aligned next to the words "MOST" and "LEAST."

The participants were asked two qualifying multiple-choice questions that would be used to group the participants together for statistical analysis:

1. Number of years of clinical practice: a. 0–5, b. 6–10, c. 11–15, d. 16–20, e. 20+
2. The number of Continuing Education courses on dental occlusion they had previously attended: a. 0–3, b. 4–6, c. 7+

To properly perform the exercise, each participant was instructed to draw a single line in ink, from the words "MOST" and "LEAST" (appearing next to each picture) to the corresponding contacts that the participant thought reflected those occlusal force characteristics. A properly completed exercise demonstrated only two lines per photograph, drawn from the two words to two different single contacts. Tests that had more than two answer lines were discarded, and any partially completed tests were also discarded. No participants were shown the correct MOST and LEAST forceful contacts, so that future testing could be accomplished without compromising the results of future testing.

Scoring

The Multi-bite computerized occlusal analysis data was used as the "answer key" to grade the contact choices of the participants (Figs. 1–6). In the two-dimensional occlusal view of the relative force data, the highest forces were colored red or pink, and the lowest forces were colored blue. In the three-dimensional view, the similarly colored column heights describe the relative MOST and LEAST forceful contacts present. Each participant's score was calculated by comparing the participant-selected MOST and LEAST forceful contacts against the measured relative occlusal force profile of each photograph. A correct contact selection (scored as a "+") occurred when the line from MOST and/or LEAST touched or nearly touched within 1 mm, the articulating paper mark that corresponded to the measured most or least forceful contact observed within the Multi-bite computerized force data. An incorrect contact selection (scored as a "−") occurred when the line from MOST and/or LEAST touched paper marks on different teeth than where the most and least forceful contacts resided, or when the ink

Table 1 The average number of correct answers for each group according to years in clinical practice and the number of occlusion courses taken. No significant difference was found between any of the groups

Average number of correct answers by time in practice

	0–5 yip	6–10 yip	11–15 yip	16–20 yip	> 20 yip	All	Random
Mean	1.528	1.476	1.520	1.318	1.636	1.534	1.50
SD	1.4038	1.2923	1.1292	1.1768	1.238	1.2361	

Average number of correct answers by number of occlusion courses taken

	0–3 courses	4–6 courses	7+ courses	All	Random
Mean	1.66	1.38	1.42	1.53	1.50
SD	0.883	0.748	0.706	1.234	
P>0.82	*	*			
P>0.76	*		*		
P>0.94		*	*		

Comparison between groups (years in practice)

yip=years in practice	*P*	
0–5 yip versus 6–10 yip	0.867205	ns
0–5 yip versus 11–15 yip	0.978179	ns
0–5 yip versus 16–20 yip	0.477757	ns
0–5 yip versus >20 yip	0.680351	ns
6–10 yip versus 11–15 yip	0.864266	ns
6–10 yip versus 16–20 yip	0.555468	ns
6–10 yip versus >20 yip	0.489988	ns
11–15 yip versus 16–20 yip	0.400081	ns
11–15 yip versus >20 yip	0.557058	ns
16–20 yip versus >20 yip	0.136142	ns

Table 2 The results of Chi-square analysis of 101 randomly selected subjects' scores. The equally low sensitivity and specificity values indicate a lack of reliability in the determination of both high and low force values using Subjective Interpretation of paper marks on the teeth

Chi-square — reliability of visual determination of force				
	Most forceful		Least forceful	
True	77		76	
False	535		536	
Totals	612		612	
Sensitivity		TP/(TP + FN)	0.126	12.60%
Specificity		TN/(TN+FP)	0.124	12.40%
Positive predictive value		{TP/(TP+FP) × 100}	12.58%	
Negative predictive value		{TN/(TN+FN) × 100}	12.42%	
Respondents=101				
Occlusal contact estimations=1224				

lines touched other contacts on the same teeth where the most or least forceful contacts resided. A "–" was also scored if the correct contacts were selected, but their MOST and LEAST designations were reversed. Each picture question was scored from 0 to 2 correct, resulting in a six-picture total score that could range from 0 to 12 correct.

Each individual score was tabled in a spreadsheet for statistical analysis (Excel 2003; Microsoft Corp., Seattle, WA, USA) grouped by the participants' qualifying question responses. Means and standard deviations were determined for the *total number of study participants (*n*=295),* the *years in clinical practice (years in clinical practice)*, and the *number of Continuing Education occlusion courses taken*. Both groups were statistically analyzed using a two-tailed Student's *t*-test with equal variances (Table 1).

One hundred and one randomly selected properly completed tests underwent a Chi-square analysis where a response was labeled *True Positive* when it correctly identified the most forceful contact and *True Negative* when it correctly identified the least forceful contact. A response incorrectly identifying the most forceful contact was labeled as *False Positive*, and a response incorrectly identifying the least forceful contact was labeled as *False Negative*. From the Chi-square results, the sensitivity, the specificity, the positive predictive value, and the negative predictive value, were all calculated (Table 2).

Results

The mean score for the entire group (n=295) was 1.534 (±1.236) correct answers out of a possible 12, or 12.8% correct. The highest score of 7 correct, was scored by one of the least experienced clinicians (0–5 years in practice; 0–3 CE courses in occlusion taken). This score (7 correct) was about 4 standard deviations above the mean, which, for a normal distribution, has a probability of 1 in 15, 787. Therefore, 7 out of 12 correct could have been obtained either by the subject demonstrating better than average Subjective Interpretation skills, or by having fairly good luck. However, there was no significant difference between any of the group means based on years in clinical practice (P>0.136–0.978), or by the number of occlusion courses taken (P>0.75–0.94) (Table 1).

The coefficient of variation (SD/mean) for each group in Table 1 was quite large, ranging from 0.743 for the 11–15 years in clinical practice group, to 0.919 for the 0–5 years in clinical practice group. When the standard deviation is nearly as large as the mean, it indicates that variation is quite large. However, the variability was not significantly different between the five differing years in practice groups or the three differing numbers of CE courses taken in occlusion groups.

From a random subset of participants (n=101), the Chi-square analysis of their scores indicated a sensitivity of 12.6%, a specificity of 12.4%, a positive predictive value of 12.58%, and a negative predictive value of 12.42% (Table 2). The subset group as a whole scored 12.66% of the answers correctly. Based

Table 3 The number of correct answers for each group selected by the years in clinical practice: 94.2% of participants scored only 3 or less out of 12 possible correct answers. Half of the participants scored either one or zero answers correctly

Number of correct answers for each group by time in practice							
# Correct	0–5 yip	6–10 yip	11–15 yip	16–20 yip	20+ yip	All	Percent
5 or more	1	1	0	1	0	3	1.0%
4	1	2	2	2	7	14	4.8%
3	4	3	8	3	29	47	16.1%
<3	30	36	40	38	84	228	78.1%

Note: The median score was 1.0 (half of the scores were either a 1 or a 0).

Table 4 The number of correct answers for each group selected by the number of CE courses in occlusion taken: 96% of participants scored only three answers or fewer correctly

Correct answers for each group by number of occlusion courses taken					
# Correct	0–3 courses	4–6 courses	7 + Courses	All	Percent
5 or more	1	0	0	1	0.99%
4	1	0	2	3	2.97%
3	4	4	6	14	13.86%
<3	29	17	37	83	82.18%

Note: This group was the 101 subjects randomly selected for the Chi-square test.

on the number of possible choices, a probability was calculated indicating that 12.5% of the answers could have been selected correctly just by chance, since the average number of choices for each question was only eight (one of eight was True Positive, and one of eight was True Negative, per picture-question). The subjects performed just 0.16% better than chance. This suggests that a score of 7 correct, which was four standard deviations above the mean, was an extremely high score (only one person achieved that) and that a score of 0 correct was only a somewhat low score. Zero correct was only about 1 standard deviation below the mean because many subjects achieved 0 correct. The median score was 1 correct, because half of the scores were either 0 correct, or 1 correct.

Table 3 shows the distribution of correct answers by years in practice. Although the group with 20+ years in practice had the most participants, the relative numbers of scores in each year in practice category were very similar for each group. In fact, 78.1% of the total scores consisted of zero, one, or two answers being correct. Thus, more than ¾ of the participants incorrectly answered at least 10 of the 12 possible answers using *Subjective Interpretation* principles to choose the contacts. This distribution of correct answers does not support the contention that clinicians with many years in practice are any better at selecting high-force or low-force contacts from the appearance of paper marks on the teeth.

Table 4 shows the distribution of correct answers of the 101 randomly selected participants grouped by the number of CE courses on occlusion taken. This distribution is remarkably similar to that of Table 3. It indicates that increased attendance at CE courses on occlusion did not improve the participants' ability to correctly select either high-force or low-force contacts using *Subjective Interpretation* of paper marks on the teeth.

Discussion

The findings of this investigation reject the Null Hypothesis that dentists can accurately determine occlusal contact relative force content by making *Subjective Interpretation* visual assessments of articulating paper mark size, color, and shape appearance characteristics. The results indicate that *Subjective Interpretation* is not a reliable method for clinicians to employ when determining the relative occlusal force content of tooth contacts. The very low means per analyzed clinician group reported (<2 correct) combined with high total *n* value (295 participants), definitively indicate that clinicians cannot determine the degree of relative occlusal force by observing paper markings (Table 1). The Chi-square analysis of 101 random tests indicates that visual inspection of articulating paper markings is a highly ineffective method of determining relative occlusal force levels (Table 2).

Tables 3 and 4 illustrate that regardless of the years in clinical practice, or the number of CE courses in occlusion taken, most study participants scored very poorly. For the entire years in clinical practice group, only 5.8% of the participants scored 4 or more correct, whereas 94.2% of the participants scored 3 or less correct. For the entire number of CE courses in occlusion taken group, only 3.96% of the participants scored 4 or more correct, whereas 96.04% of the participants scored 3 or less correct. Both tables confirm that the employing of *Subjective Interpretation* will likely lead to incorrect clinician contact selection in the determination of contacts as being high force, or low force. This overall poor performance by this large group of clinicians is directly related to the fact that paper mark size and color depth appearance characteristics do not, reliably illustrate to the clinician in any way, differing levels of relative occlusal force.[8–13] The results of this study bring into question both the widely advocated belief in the principles of *Subjective Interpretation*,[1–7] and the widely held belief that articulating paper markings have force descriptive capability.

As this is the first-ever-attempted study assessing whether *Subjective Interpretation* of articulating paper markings is a reliable method for clinicians to use, the results cannot support or refute the findings of earlier studies regarding *Subjective Interpretation* accuracy (there are none; *Subjective Interpretation* was always believed to be reliable despite having never been tested in any scientific analysis). However, the results do support recent articulating paper mark studies that found no correlation between the appearance characteristics of articulating paper markings and applied occlusal load.[11–13] This study's findings reveal that clinicians will make numerous occlusal force content *Diagnostic Errors* when observing varying shapes and sizes of articulating paper marks. This is likely due to the fact that there is low correlation between paper mark appearance characteristics and applied occlusal load. The articulating paper's inability to describe relative occlusal force[11–13] combined with the clinician's inability to determine relative occlusal force by observing the paper marks, explains why the overall results of this investigation are so poor.

It has been written that differing articulating paper markings can vary, and may not be repeatable.[3,10] Figures 1–6 illustrate this wide variability of the size and shapes of articulating paper markings. Contrary to what has been advocated, correlating paper mark size to force description (large dark marks are forceful contacts and light small marks are low force contacts),[1–3,5–7] it is clear when observing Figs. 1–6 that using size to describe occlusal force is a highly inaccurate method. In Fig. 1, on the mesiolingual aspect of tooth #9, there is a very small mark present compared to a much larger mark present in the mid-lingual aspect of tooth #10. However, the force profile of #9 mesiolingual is much greater than that of the #10 mid-lingual contact. Also in Fig. 1, tooth #8 lingual has a series of smaller marks than those present on tooth #9, but the combined individual force percentage of the marks on tooth #8 is equal to the total force percentage of tooth #9. This kind of detailed occlusal force information cannot be obtained for patient treatment considerations, by just looking at the markings. It can only be gained through using occlusal measurement technology to assess the occlusal force distribution of each occluding contact and tooth. In Fig. 2, there are large, broad paper marks present on teeth #4 and 5, but the highest force contact is where there are small marks, lingual to the central fossa of tooth #3. Note that tooth #5 has equal total force percentage to tooth #3, despite the visible mark size disparity. Figure 2 illustrates a "best example" of how mark size cannot reliably describe occlusal force. Tooth #4 has a very large red mark on its palatal cusp, but it measures as very low relative force despite its size. In Fig. 3, the highest and lowest force contacts share almost equal size (mesiobuccal cusp tooth #2 is the highest; distal marginal ridge tooth #4 is the lowest), which contradicts what has been written about equal mark size and load; equal size marks should represent equal loads.[1–3,5–7] In Fig. 3, these two equal size marks represent very different loads. This image confirms the findings of the Carey study that a single mark size can represent many loads.[11] The "halo" contact present in Fig. 4 on tooth #3, which has been advocated to represent a high force contact (because the ink is missing from the middle), is actually a very low force contact. Alternatively, the small marking on the distal of tooth #5 is representing a very high force contact. Figure 5 contains a *false positive mark* present on the mesiolingual aspect of tooth #3 where there is no occlusal force present. The clinical reality that articulating paper leaves false positive marks, regardless of any reported capability minimizing false positive markings, does compromise a clinician's ability to truly know where tooth contact occlusal force actually exists. In Fig. 6, the scratch-like marks on the distopalatal aspect of tooth #4 are significantly more forceful than the much larger red/black ink mark present on tooth #5. These six figures clearly illustrate that mark size does not adequately inform clinicians of which tooth contacts contain high or low force.

The inability of paper mark size to describe load demonstrated in Figs. 1–6, combined with the results of this investigation and other present-day paper mark/force reporting studies,[11–13] suggests that there is a definitive need for implementing a measurably accurate, and reproducible occlusal indicator standard, where clinicians do not solely employ *Subjective Interpretation*. The authors contend that codes of medical ethics and quality of care standards for the human dental patient, requires dental medicine to change to the way occlusion is diagnosed, analyzed, and treated.

Computerized occlusal analysis technology has been shown to be capable of repeatedly measuring relative occlusal contact force.[18] This technology eliminates the subjectivity of clinicians judging paper mark appearance size and color characteristics for occlusal force content. It replaces that subjective process with an *objective process* that is based upon how varying occlusal contact force induces varying electronic resistance changes within the recording sensor at the occlusal contact surface interface.[16] These resistance changes are sequenced in the order that the tooth contacts sequentially occur in 0.003-second increments, and graded across 256 levels of relative force. By using this technology, regardless of a given occlusal contact's paper mark appearance characteristics, a clinician can properly analyze, target accurately, and measurably lessen occlusal force excess without employing any subjectivity.[15–17]

Computerized occlusal analysis technology will predictably improve how occlusal force excess is located and treated on natural teeth, dental restorations, and dental implant prostheses. This patient-affect improvement results from the measurement technology eliminating the clinicians' inability to choose forceful contacts by looking at paper marks. This would be especially significant during the performance of occlusal adjustment procedures. Because there is a severe lack of clinical accuracy using *Subjective Interpretation*, there appears to be a clinical need for abandoning this *supposed force detection* method for one that involves occlusal measurement technology.

Study Limitations

In this study, only maxillary photographs were used because the computerized occlusion relative force data are graphically displayed on the maxillary arch. This provided the best relative force correlation with the paper mark contact locations for scoring purposes. Additionally, five of six photographs were of the right posterior quadrant, which occurred randomly through the course of obtaining photographs for the study.

A second limitation was that, unlike the clinical environment, there was no patient occlusal perception input given to the participants regarding which contacts felt "high" or "low." Additionally, no occlusal history per picture was disclosed regarding occlusally-induced tooth pain, hot or cold sensitivity, tooth mobility, or advanced gingival recession. Clinicians often use patient input and existing clinical tooth presentation to narrow down which tooth is perceived to be the most forceful. This would not necessarily yield which contact is the most forceful one, but might assist the clinician in isolating where occlusal force excess may exist. It should be noted that there are no published studies showing patients can reliably detect occlusal force excess using occlusal contact feel. Because no such patient input was available to the participants, they were required by the study design to solely rely on their *Subjective Interpretation* skills in selecting forceful and non-forceful contacts.

Another limitation was that the time allotted for the respondents to answer the six questions was limited to 20 minutes. This is actually much longer than they would have had available in the clinical environment. Usually, after a patient taps on the articulating paper, the clinician assesses the marks visually, and makes a subjective determination as to which contacts are problematic. That process might require 30 seconds to complete, after which one or more marks are selected for treatment. The clinician would then ask the patient (something like) "how does that feel?" Depending upon the patient response, the process could be repeated for further corrections. Since no treatment was part of the study, participants had ample time to complete the *Subjective Interpretation* exercise.

Another limitation was that the articulating paper strips used in the study might not have been the same type used clinically by some of the participants. This could affect some of the participants' perceived ability to read the markings due to unfamiliar appearance characteristics. Accufilm is a commonly employed occlusal indicator that has been used in prior occlusal marking research. It was used because it reportedly leaves the least number of false positive marks (a false positive mark is present in Fig. 5).[9]

Potential Clinical Relevance

The potential clinical relevance of this investigation's finding is that clinicians using *Subjective Interpretation* of articulating paper markings, are likely to regularly make occlusal contact force excess diagnostic errors in determining locations of occlusal contact force excess. These diagnostic errors will directly lead to the same clinicians selecting incorrect tooth contacts for occlusal adjustment treatment. Incorrect contact selection will likely result in a number of potential untoward occlusal adjustment complications:

1. The removal of excessive tooth structure from areas of teeth that do not need occlusal force reduction, leading to possible weakened enamel fracture and thinned enamel tooth sensitivity.
2. The thinning out and weakening of occlusal dental materials present on various types of dental prostheses. This thinning and weakening could lead to early material failure and shorten the lifespan of the involved prosthesis.
3. The potential for destabilizing a patient's occlusal comfort level, leading to the appearance of occlusally activated tooth pain, and/or the sudden onset of previously absent temporomandibular disorder symptoms.
4. The potential for the clinician to not treat the true areas of occlusal force excess because the paper marks do not appear to the clinician to be "*forceful looking*." This lack of excess force removal will lead to the ongoing existence of localized, long-term, occlusal force excess on some tooth contacts. This could lead to the development of tooth structure fracture, occlusal wear, tooth mobility, abfraction formation, gingival recession, periodontal bone loss, and peri-implant bone loss.

Because paper mark appearance characteristics have never been shown in studies to provide the clinician with an accurate description of occlusal contact force content,[8–13] continuing to advocate the use of *Subjective Interpretation* as an effective method of selecting forceful occlusal contacts for treatment, will likely result in the occurrence of many common occlusal treatment complications often seen by practicing clinicians.

Conclusion

The findings of this investigation indicate that *Subjective Interpretation* is a very poor method of determining the relative occlusal force content of tooth contacts. The very low scores observed in this study indicate that clinicians are unable to reliably differentiate high- and low-force contacts by inspecting the appearance characteristics of articulating paper marks made by contacting teeth. The very poor performance of this large group of clinicians suggests that *Subjective Interpretation* should be replaced with an objective, reliable, measurement-based, accurate method for determining tooth contact relative occlusal force variances.

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